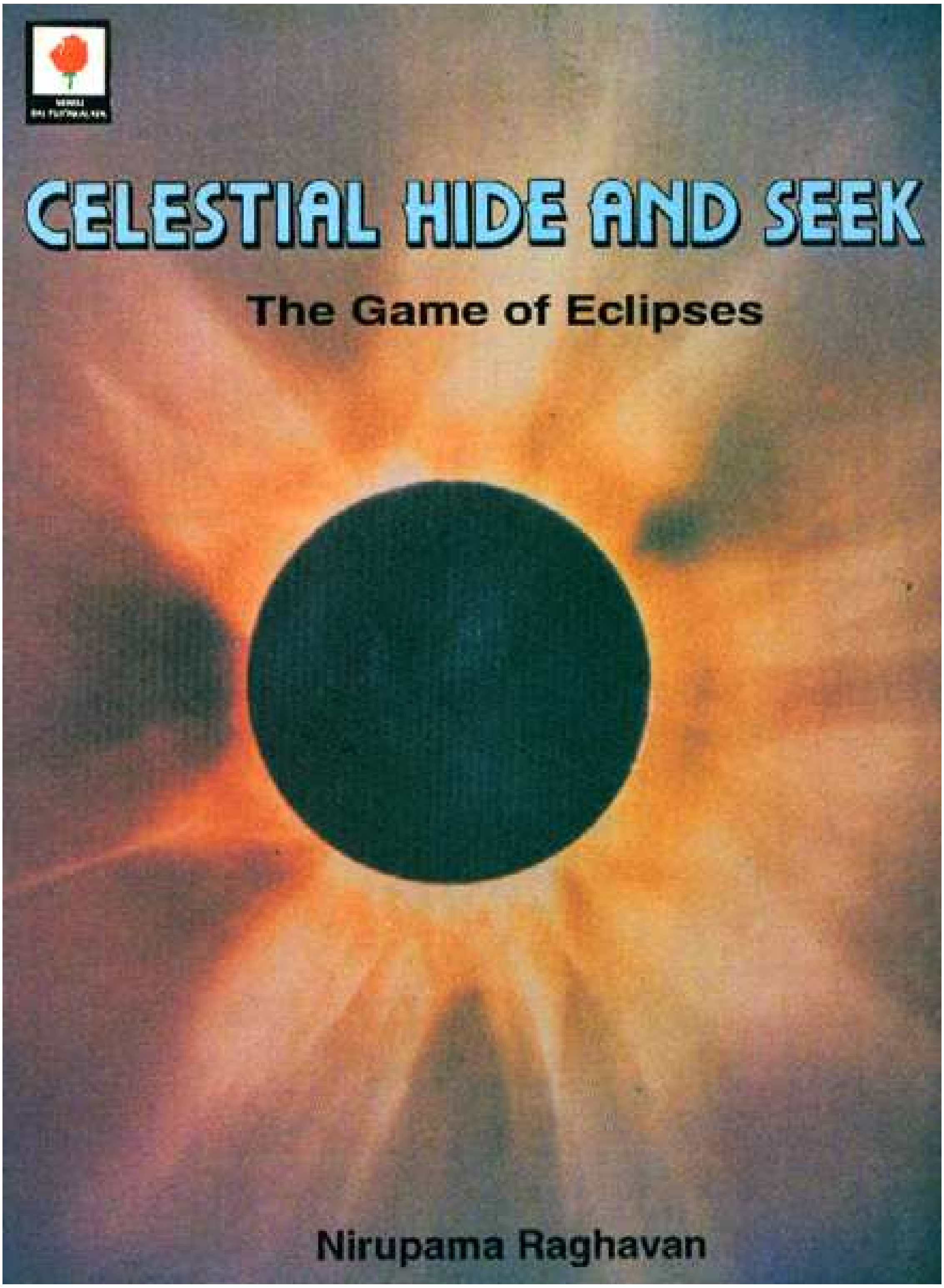

CELESTIAL HIDE AND SEEK
The Game of Eclipses
Nirupama Raghavan

CONTENTS

1. THE PLAYERS

Mother nature is fond of playing games, just like us. When scientists observe a natural process, they try to understand who the players participating in the game are; what rules are being followed; and who the umpire is! Eclipses are one of the most visible games played by nature. They have been among the earliest games of nature observed by humans.

It must have been obvious to early man that the sun was a player in a solar eclipse and the moon, in a lunar eclipse. Identifying the other players took thousands of years of careful observation and analysis. Today we know that both the eclipses are games played by the same three participants, the sun, the moon and the earth. Let us get acquainted with the players, one by one.

The Sun

The first thing we notice about the sun is that it shines bright and brings warmth. The second thing that we see is that it disappears every day, followed by night but reappears the following day without fail! In fact, we can count the beginning of each new day with sunrise.

If we observe the sun over several years we also notice another pattern. In a very regular way, the warmth we receive from the sun increases, decreases and increases again. This cycle of seasons is even more dramatic than the night-day cycle. The entire scenery around us

changes in rhythm with the increase and decrease of warmth from the sun. The remarkable control that the sun has on all living things was well known to our ancestors. No wonder most early civilizations worshipped the sun.

How Did it Get that Way?

It all began about 4,600 million years ago, when in one part of the Milky Way Galaxy—our home galaxy—a huge cloud of gas and dust, made up mainly of hydrogen, started contracting under its own gravity. Why exactly this happened; we are not sure yet, but the cloud must have been extremely huge, at least a thousand million, million, million, million, million kilograms in mass and ten million, million kilometres in diameter!

As it contracted, the atoms in the gas cloud collided with each other more often and more vigorously. This raised the temperature of the cloud from a freezing initial temperature of -173 degree celsius. The cloud continued to flatten as it contracted and got hotter and hotter. Soon, in about 30 million years (that is 'soon' in astronomy!) the central part of the cloud—some 1.5 million kilometres in size—had become very compact. Deep inside this core, the temperature became incredibly high—more than 15 million degrees!

But long before this temperature was reached, the hydrogen atom was stripped of its only electron and was dashing around as a proton. Whenever one proton came anywhere near another, electrical forces pushed them away from each other, because they both carried the same kind of charge. But when the temperature reached 15 million degrees at the centre, they were moving around so fast that electrical forces just could not stop them. They crashed into each other and stuck together in a process called nuclear fusion, producing a new element. This was an important event. Two protons separately had just a little more mass than two protons bound together. Where did this extra mass go? It got converted into energy—light and heat. The cloud of gas now started shining—and a star, our sun, was born. The pressure of heat from nuclear fusion deep inside prevented the gas cloud from shrinking any further.

The sun has been producing energy by nuclear fusion at a nearly constant rate since that time, slowly converting its supply of hydrogen into helium. It has been sending out nearly the same amount of light and heat, in all these thousands of millions of years. So, the sun, the first

Fig. 1 : A swirling cloud of gas and dust in the process of planet formation

player in the eclipse game, has three very important qualities.

Firstly, it is very very massive—more than ten to the power of thirty kilograms, i.e. 1 followed by 30 zeros!

Secondly, it is huge in size, about 1.4 million kilometres in diameter.

Thirdly, it makes nuclear energy deep inside it, that makes it shine.

We have seen how and why the sun gives off heat and light. But we still must find out why the sun disappears every day to reappear on the next and why the warmth of the sun seems to increase and decrease so regularly over the year. For that we must get to know the second player.

The Earth

We live on the earth. From just observing the sun rise and set every day, you would come to the conclusion that the earth is standing still and the

sun is going round it once every 24 hours. We would observe the same thing if we suppose instead that the earth spins on its own axis. Given the fact that we do not feel the earth spinning but 'see' the sun rising and setting, the idea of the sun going round the earth seems to agree better with our senses. That is exactly what ancient man thought!

However, other ideas were also put forward. In the 2nd century B.C., Aristarchus, a Greek astronomer, placed the sun at the centre, with the earth going round. His reasons were philosophical. He felt that a bright luminous body like the sun belonged in the centre. In the 5th century A.D., the Indian astronomer, Aryabhata stated that it is the earth that rotated and not the sun, the moon and the stars. He pointed out that, to a passenger in a boat travelling down the Ganga, the trees on the bank appear to go in the opposite direction. But astronomers after him refuted this. Brahmagupta asked, "If this was true, how could a stone thrown up, fall back in the same place?" Aryabhata's idea of a spinning earth was rejected!

Fig. 2 : Space view of the earth—satellite photograph

A thousand years had to pass before the nature of the earth and its movements could be understood and verified. The earth is indeed spinning on its own axis. A stone thrown up in air carries the velocity of the spinning earth along with it. That is, not only is it moving up but also moving forward in the direction of the spinning earth and therefore falls back to the same place! The truth of these statements have been directly proved only in the space age. Satellites are launched eastwards so that the velocity of the spinning earth adds to the launch velocity.

The explanation for the other pattern—of increasing and decreasing warmth—had also to wait for Copernicus, Galileo, Kepler and Newton. They firmly placed the earth where it really belongs, as a member of the planetary system going round the sun once a year, even as it is spinning on its own axis once a day. Interestingly, its axis of spin is tilted to the plane of its orbit. It is this tilt that is responsible for the pattern of increasing and decreasing warmth that we see round a year and all the intricate changes on the earth connected with it.

How Did the Earth Come to be in its Present Form?

We have to go back once again to the very beginning, 4,500 million years ago, when the sun had just started to shine because of nuclear energy deep inside itself. The rest of the flattened gas cloud was still swirling along with the sun. At many places in this cloud, matter was gathering in clumps. These were however, much smaller than the central mass that had started to shine. Even as they were growing in size by capturing nearby matter, they kept spinning and revolving around the central star, in the same way as the original material in the flattened cloud had. By now most of the matter was part of one clump or another. They collided with each other and formed larger clumps. As the central star (the sun) started to shine, fierce radiation emerging from it swept away most of the left over gas and dust from the swirling cloud. The larger clumps remained, but could not grow any larger, as there was no more matter left around them to gather. Even the largest clumps could not produce the high temperature needed to make nuclear energy and shine as stars. These clumps therefore had to be content in becoming planets without any light of their own, dependant on the sun for all their energy needs.

Our earth is one of them, the third one from the sun. It is very likely that a collision with another large sized body knocked its axis off the vertical and gave the earth the second rhythm—that of the seasons.

Ever since, the earth has been spinning, causing night and day and going round the sun once a year, soaking up its energy, to fashion this beautiful space home for us.

So, there are three things to remember about the earth—the second player of the eclipse game.

It is relatively small, being only 12,756 km in diameter, and having a mass just one thousandth that of the sun.

Secondly, it makes no nuclear energy and therefore has no light of its own.

Thirdly, it spins on its axis which is tilted to its orbital plane, once a day and also goes around the sun once a year in an orbit.

We still have to get acquainted with the third player, the moon.

The Moon

The moon is the most prominent object in the night sky. If you observe the moon for a few nights in succession, you will notice that it changes its shape every night. More careful observations indicate that it stays in the night sky for a different duration every night. On a full moon night it rises in the east as the sun sets in the west and you can see it throughout the night. On some nights it is already high up in the sky at sunset and sets early in the night. On others it rises late in the night. That is, the position of the sun and the moon with respect to each other in the sky keeps changing from night to night. On a full moon day the sun and the moon are the most widely separated—they are opposite to each other. On a new moon day, when the moon is not visible at all, they appear the closest in the sky. Since the moon does not have light of its own and is borrowing the light of the sun to shine, its shape in the night sky depends on the sun—earth—moon geometry. This geometry decides what fraction of the lighted moon is visible from the earth.

Our ancestors in India noticed one more rhythm. The pattern of stars that is visible near the moon every night changes regularly. Twenty seven different groups of stars can be seen near the moon in succession, before it is seen near the same pattern of stars once again. These are the 27 nakshatras. But its shape is now different! It takes 2¼ days more before the moon has the same shape, but by that time the star pattern nearby has changed!

As in the case of the earth, it was only in the 16th and 17th century that a full understanding of the motion of the moon came. It became known that the moon spins on its axis, going round the earth and along

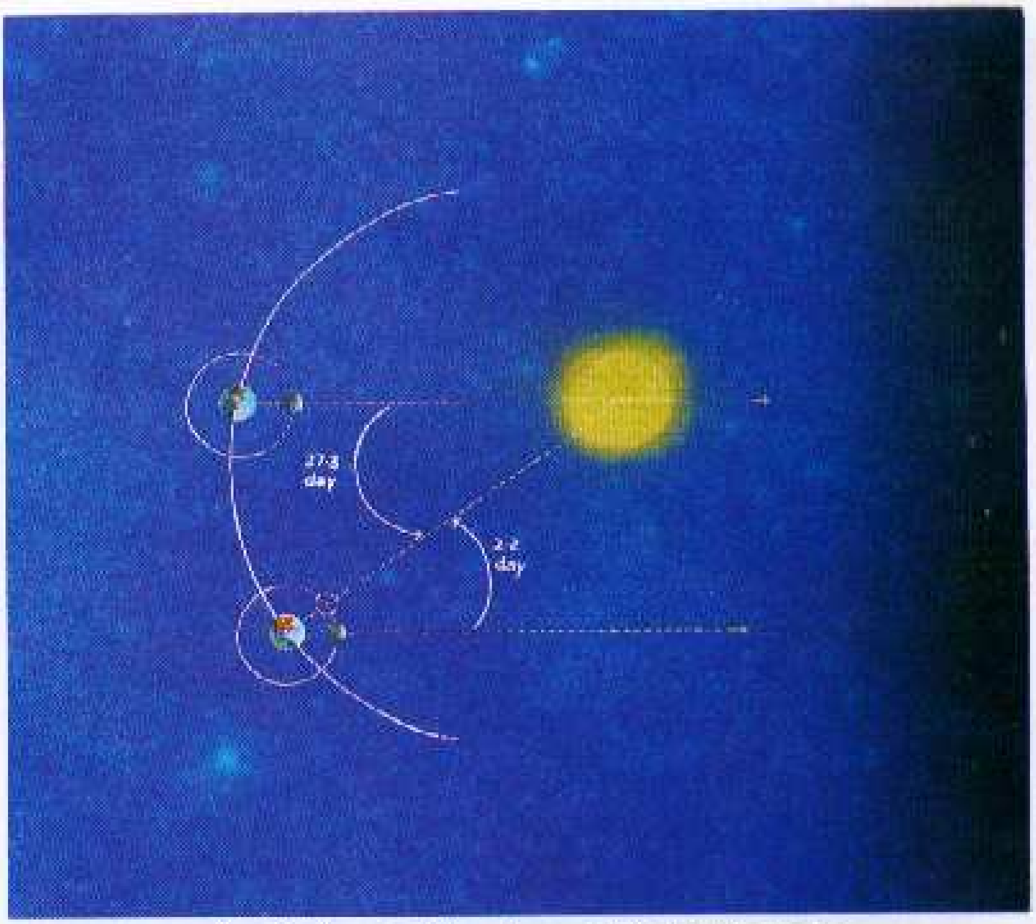


Fig. 3 : The nakshatra-phase relation for the moon

with it also going round the sun! If you attempted something like that you would be giddy! It takes $27\frac{1}{3}$ days to go around the earth, so that the same set of stars are visible near it after every 27 nights. But in this time the earth moves along its orbit by about 27 degrees. So the moon too has to move along its orbit around the earth for approximately $2\frac{1}{4}$ days longer, to have the same sun—earth—moon geometry and therefore the same shape.

The moon also spins on its axis once exactly in $27\frac{1}{3}$ days, the time it takes to go round the earth once. This has the consequence that, we on the earth, always see the same face of the moon. It is only when spacecrafts circled the moon from 1959 onwards, that we have come to know what the far side of the moon looks like. It bears the same look as the near side, pitted with craters, only less so.

How Did it Get That Way?

Well once again, we have to go back to the beginning of the solar system. Although it is not yet certain that the moon was formed along with the earth and the other planets, this is the best guess that scientists have today. It is based on the rock samples brought back by space missions from the United States of America and the then Soviet Union. One of the rocks brought back had an age of 4,500 million years, dating back to the time when the solar system was being formed. So, the moon may also have been formed at that time from material which formed a clump in the vicinity of the earth. In fact, it must have been competing with the earth to gather up the nearby material. However, the earth won by gathering up much more matter and becoming more than three times larger than the moon. This proved to be a very important advantage as it enabled the bigger earth to have a much larger gravity and hold on to its early atmosphere which played a crucial role, later in the evolution of life.

The gravity of the less massive moon was too small and the moon lost all its atmosphere, leaving it an airless, waterless, dead place. Its smaller mass and its nearness to the earth has caused it to be tied to the earth, by gravitational pull, going around the earth as its satellite. Perhaps because of the conditions that existed when the moon was being formed, or due to later events, the plane in which the moon goes round the earth is slightly different than the one in which the earth goes round the sun. So the moon, the third player in the eclipse game, has the following important attributes.

First of all, it is much smaller, being less than one-third the size of the earth. It is an airless, waterless dead world.

Secondly, it is a satellite of the earth, going round it once every $27\frac{1}{3}$ days and tagging along with it as it revolves around the sun. Its orbit around the earth is in a plane that is slightly tilted to that in which the earth itself is going around the sun.

Thirdly, like the earth, it does not have light of its own and reflects the light of the sun when it shines.

Now we know all the players!

Let's Make an Earth—Moon—Sun System

The sun, the earth, and the moon have very different sizes. There are many photographs of the sun, the moon and the earth individually, there is even one of the earth and the moon together, taken by the

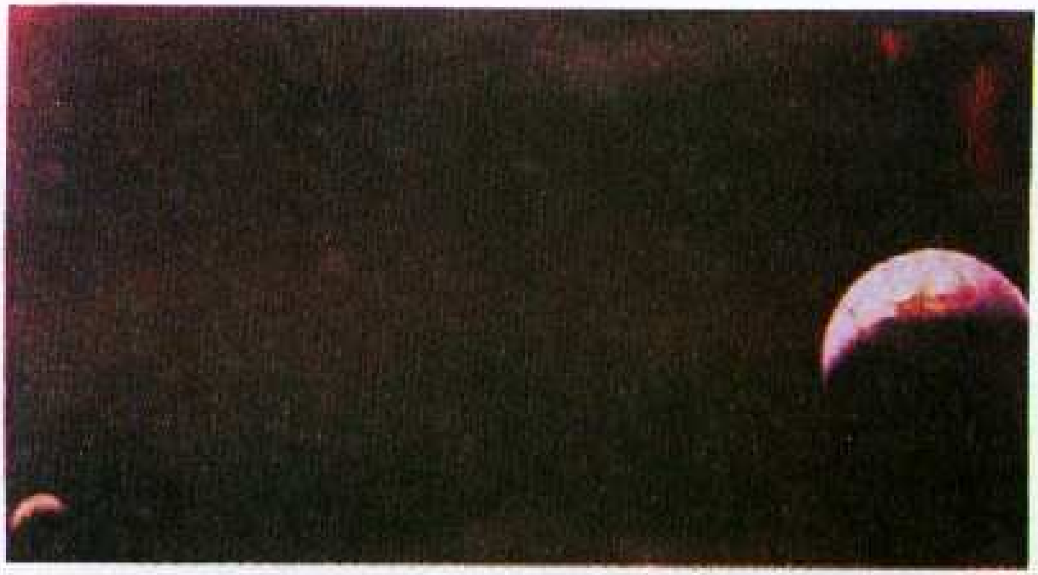


Fig. 4 : Earth and moon—photograph by spacecraft Voyager-2

Voyager spacecraft. But there is no photograph of all the three together! In this activity you can construct a scale model of the earth—moon—sun system.

Use a scale of 1 cm = 50 thousand km. The diameters are:

	Actual	*Model* (approximate)
Sun	1.4 million km	30 cm
Earth	12,756 km	2.8 mm
Moon	3,480 km	0.7 mm

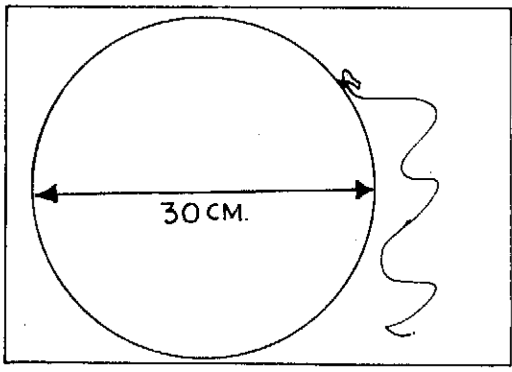
The distances are:

	Actual	*Model* (approximate).
Earth - Sun	149.6 million km	30 m
Earth - Moon	3,84,400 km	10 cm

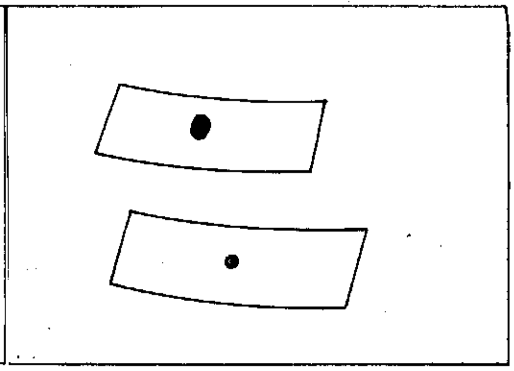
What you need

A large yellow balloon (The sun)
A moong seed (The earth)
A mustard seed (rai) (The moon)
A ball of string at least 35 m long
Cloth clips, sticking tape

What to do

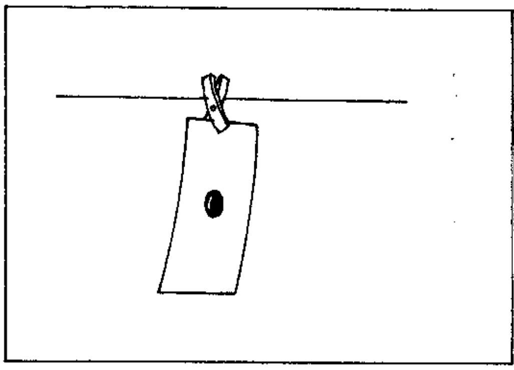


1. Blow up the balloon to 30 cm diameter.

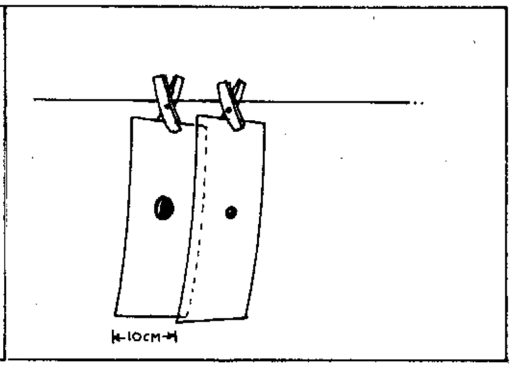


2. Secure the moong and mustard in 1" lengths of sticking tape.

3. Tie the balloon to one end of string.



4. Measure 30 m long string from the balloon. Clip the taped moong seed.



5. Measure another 10 cm from the moong. Clip the taped mustard seed.

6. Stretch the string to full length to view the entire model of the sun, the earth and the moon.

See how small the earth and the moon are compared to the sun and how very very far away!

Note the other things that come to your mind when you see the three players in front of you. May be some of your questions will be answered as you read on.

2. THE RULES OF THE GAME

In any game of hide and seek the players are moving around. The celestial hide and seek game is no exception. The players move here too, but in a regular and predictable way. The earth goes round the sun in the same direction always, and takes the same time to do so. This is true of the moon's motion around the earth as well. By observing them carefully, we can construct a picture of how they move. But why do they move in that precise way?

Gravity is Everywhere

You may remember that the story of the solar system began 4600 million years ago, in a huge cloud of gas and dust. This cloud started contracting under its own gravity. What is this gravity? Anything you throw up, falls back to the earth. Why? This is the question that an English physicist, Isaac Newton asked himself in the seventeenth century. The object thrown up does not wander anywhere but falls back on the earth! So, he reasoned, that the earth must be attracting these objects. He further reasoned that the source of this attraction must be the mass of the earth. But the object that is thrown up has mass too. Does not that mass have the same ability to attract? Of course it does, said Newton. But its mass is so tiny compared to that of the earth, that its ability to attract is proportionately tiny.

Then Newton's ideas took a big leap. He said that this attraction between masses should extend even into space and reach all the way to

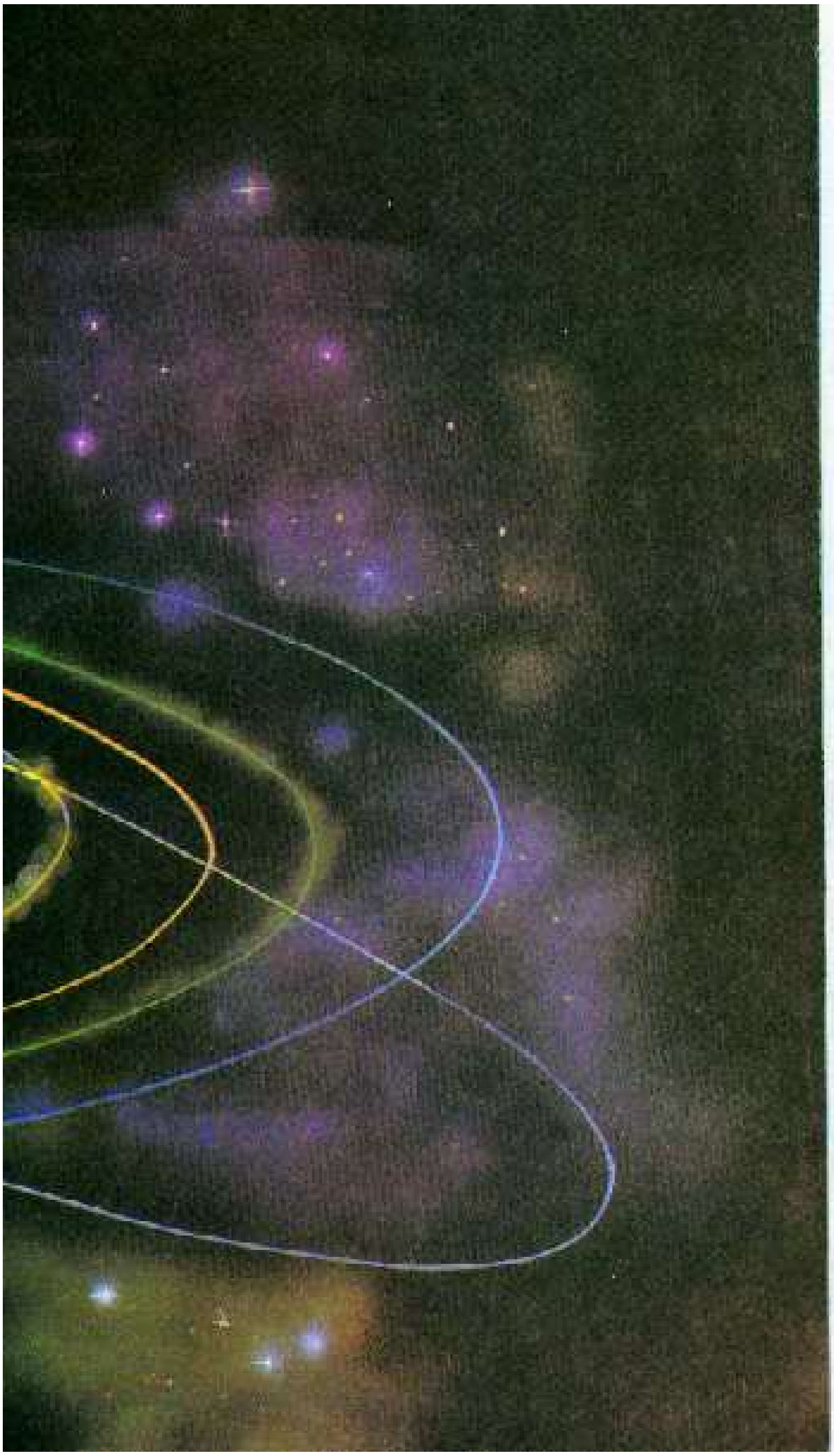


Fig. 5 : The solar s

the moon! He calculated the attraction that the moon would have on the earth. From this he could correctly predict the times when tides will be produced in the different oceans of the earth due to the gravitational pull of the moon.

This was a remarkable success for his idea of attraction between all objects. For the first time, a law of nature was found to be true in a place outside the earth and that is how we got the concept of gravitation. Since that time it has been found that gravitational attraction is present, wherever objects with mass are present. This attraction is effective over huge distances, keeping together not just the solar system, but the entire galaxy, clusters of galaxies, and all of the known universe. Just as Newton had stated, it is found that as the separation between the masses increases, the force of attraction between them decreases.

Remember, about 4,600 million years ago, it was gravitational attraction that was responsible for making the gas cloud contract and form the sun in the middle with 99 per cent of the mass. Today the sun exerts the gravitational attraction due to this large mass on all planets including the earth. This keeps the earth moving around the sun in a regular manner. The moon could have also become a planet circling the sun, but it was formed too close to the earth. It is so near, that the earth's attraction on it is many times more than that of the sun, despite the sun being a thousand fold more massive. So the earth has 'captured' the moon in its own gravity and makes it go around itself. The other planets in the solar system attract the earth and the moon too. But, they are all too far and not very massive and so the strength of their attraction is quite small. They only make a small difference.


Fig. 6 : Isaac Newton—17th century English scientist

The shape of the path or orbit in which the earth moves around the sun is controlled by all these attractions. It is an ellipse. An ellipse is a flattened

circle. The extent of this flattening is expressed by its eccentricity. The eccentricity is zero for a perfect circle. It increases as the flattening increases. The sun is not at the centre of the ellipse along which the earth goes around it. It is slightly to one side of the centre, at one focus of the ellipse. Similarly the moon goes around the earth, also along a tiny ellipse and again the earth is not at the centre of this ellipse. However, this ellipse is flatter than the ellipse along which the earth travels.

The gravitational attraction not only controls the shape of the orbit, but also the time it takes for the earth and the moon to go round once. The time period is governed precisely by the size of the ellipse and the attracting masses. These are tough rules!

So the rules of the game are:

All masses attract each other.
The strength of attraction increases as the mass increases.
The strength of attraction decreases as the distance increases.
Who controls them? Isaac Newton? No! Gravitation.

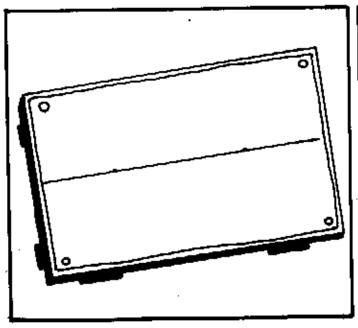
Let's Make an Orbit

Scientists use the word orbit to describe the precise path in which a body moves. We have seen that the earth and the moon move in ellipse-shaped orbits. So let us make an ellipse–shaped orbit.

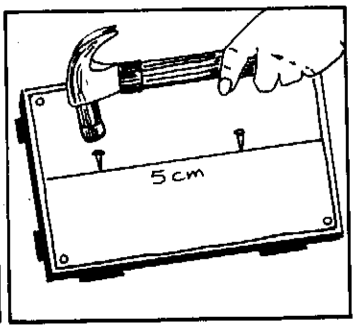
What you need

A large sheet of paper
A cardboard of same size
Twine, about 20 cm long
A pencil, two nails/thumb tacks, paper clips

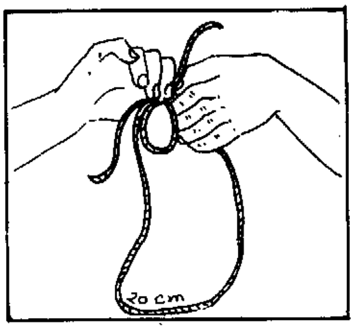
What to do



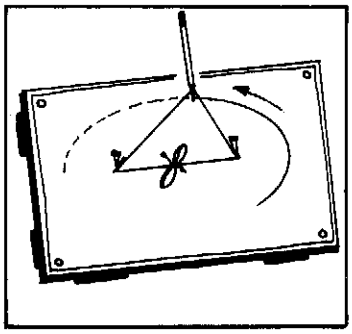
1. Clip paper to the board. Draw a line through the centre of the paper.



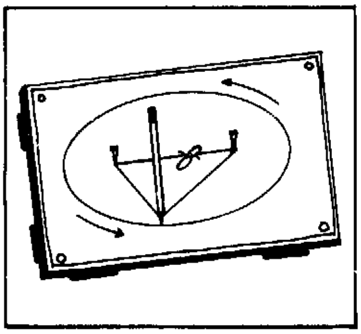
2. Hammer firmly two nails near the centre of the line.



3. Form a loop with the 20 cm twine.



4. Stretch a loop with pencil, around the nails.



5. Draw an ellipse, taking care to keep the tension in the twine uniform.

Repeat drawing with larger/smaller loop length. This changes the eccentricity of the ellipse.

What to do

1. Clip paper on to the cardboard. Draw a central line.
2. Place firmly two common pins 5 mm apart on the line.
3. Stretch 30 cm loop of sewing thread around the pins with pencil.
4. Draw an ellipse. This is the shape of the orbit of the earth. The position of the pins show the position of the two foci of the ellipse.
5. Remove the pins. Draw the sun at the position of one of the pins.
6. At one place on ellipse draw a slightly flattened circle 5 mm in diameter. This is the orbit of the moon.

You have now drawn an ellipse! This is the shape of the orbit in which the earth goes around the sun and the moon around the earth. The eccentricity of your orbit is given by

Eccentricity = Distance between the nails/Length of the loop

You can draw an ellipse with the eccentricity of the orbits of the earth or the moon. Use a scale of 1 cm = 10 million km. The eccentricities of the moon and the earth orbits are as follows: Earth—0.0167; Moon—0.0570.

See how the orbit of the earth is very nearly a circle as indeed the orbit of the moon is.

3. SHADOWS

Whenever there is a source of light, we see shadows. Objects that do not allow the light to pass through, cast their shadows. Shadows form on the wall, on the floor, on all kinds of surfaces. The only condition is that this surface must be in a direction opposite to the direction from which the light is falling on the object. If the light is bright, you see a sharp shadow. If there is more than one source of light then there is more than one shadow. You must have all seen how each player in a night time cricket match casts four shadows—one for each of the four giant lights! Do you think shadows are cast in space? Of course they are.

In the solar system, the sun is the only object that has light of its own. Its light falls on all the planets and their moons. Each casts a shadow in space in a direction opposite to the direction of the sun. Because the distance from the sun is so large, these shadows are very long. But where do they fall? Usually nowhere, as there are no objects within the shadows. But distances between a planet and its moons are small compared to distances between planets or distances of the planets to the sun. So the shadow of a planet can fall on one of its moons; or the shadow of one of the moons can fall on its mother planet.

That is what happens between the sun, the moon and the earth. But remember that the moon and the earth are in constant motion with respect to the sun and with respect to each other. So the shadow of one falls on the other only on some occasions and that too for a short time. The important question is, when?

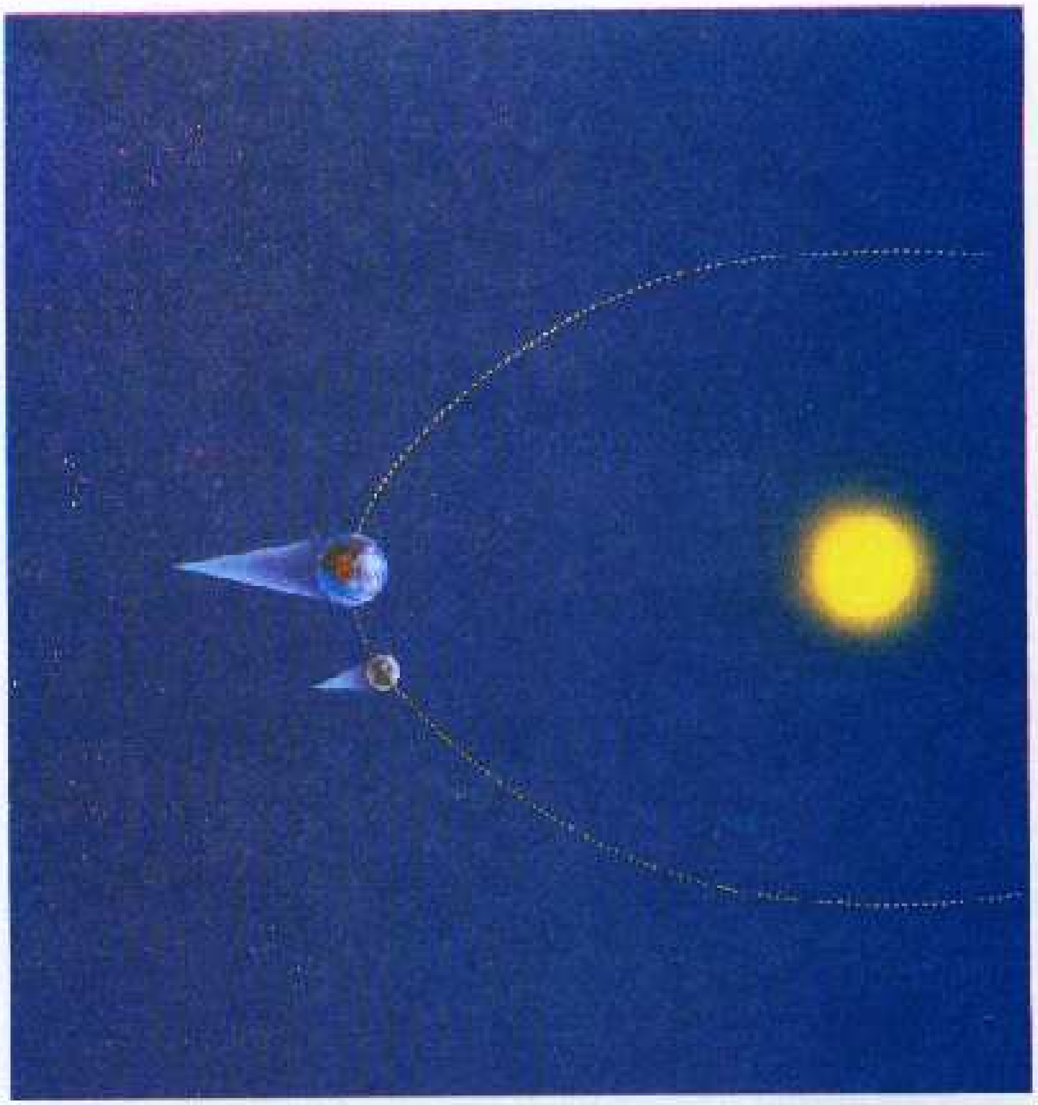


Fig. 7 : Shadows in space

Shadows are cast in a direction exactly opposite to the direction of the sun. So, if the shadow of the earth has to fall on the moon, it has to be in a direction opposite to that of the sun. We have found, what scientists call, a condition for an eclipse. In this case the sun, the earth and the moon are lined up in that order and the shadow of the earth falling on the moon causes a lunar eclipse. But there is another way in which they can be lined up—the sun, the moon and the earth in that order. In this line-up, the sun and the earth are on opposite directions

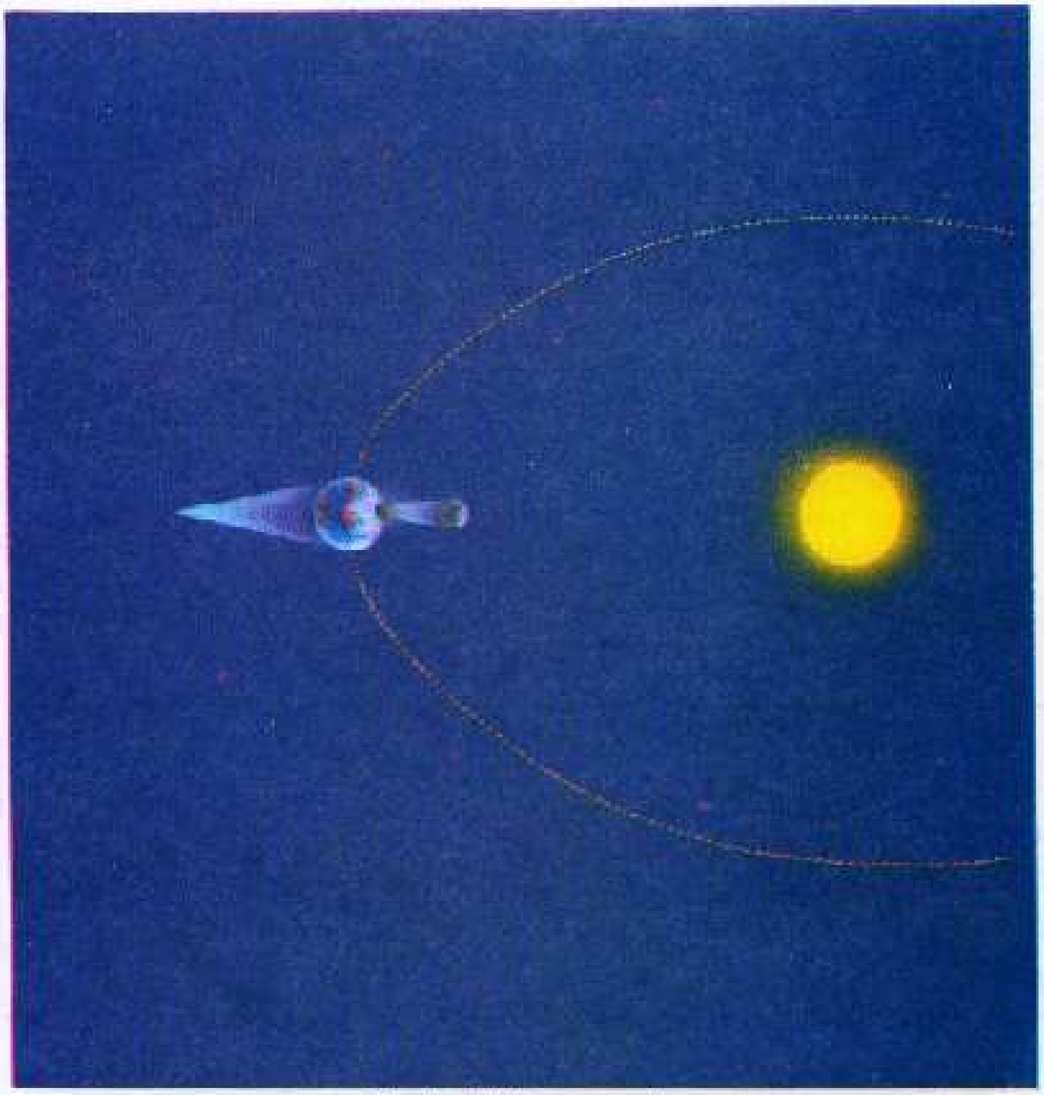


Fig. 8 : Shadow on earth

with respect to the moon. Now the shadow of the moon can fall on the earth causing a solar eclipse.

We must also check if the shadow of one is long enough to fall on the other. The earth is a much larger object and casts a much longer shadow, well beyond the orbit of the moon. This is not always true for the shadow cast by the much smaller moon. It misses the earth sometimes. So even though the sun, the moon and the earth may be lined up, no shadow is cast on the earth. We have found the second

condition for an eclipse. The distance between the earth and the moon must be shorter than the length of the shadow!

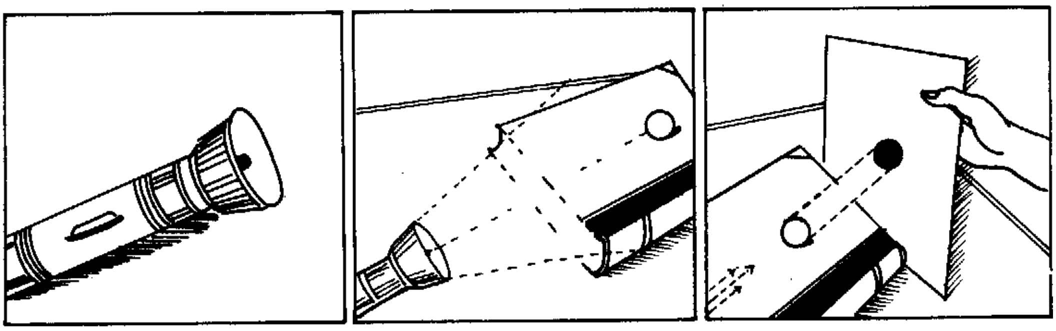
Let's Play with Shadows

If you look at a shadow carefully, you can see two outlines. One contains the darkest part of the shadow and is called the umbra. This dark middle is surrounded by a fuzzy border, called the penumbra.

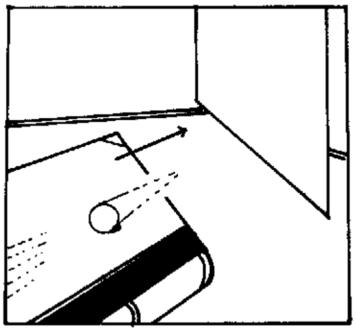
What you need

A standard torch
A plastic bead about 1 cm in size, preferably white
A plastic bead about 3 mm in size, preferably white
Several note books
White card 5 cm by 5 cm (back of a greetings card!)

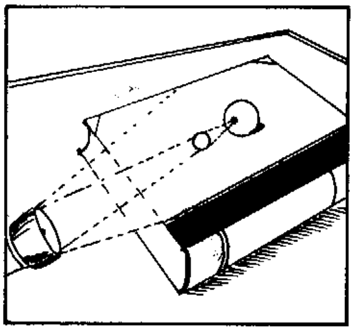
What to do



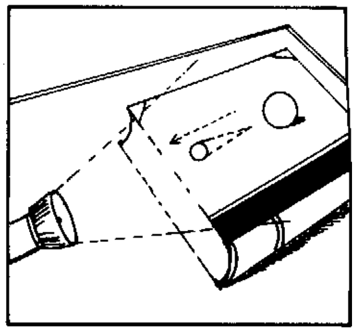
1. Lay the torch on the floor on its side.
2. Place the large bead on the stack of note books about 8 cm away from torch. Add or take away note books, so that the centre of the bead and the bulb of the torch are at the same height.
3. See the shadow of the bead by holding the white card at 3 cm from the bead. Notice the umbra and the penumbra.



4. Take the card further away from the bead slowly till you can no longer see the umbra. The shadow of the bead ends there.

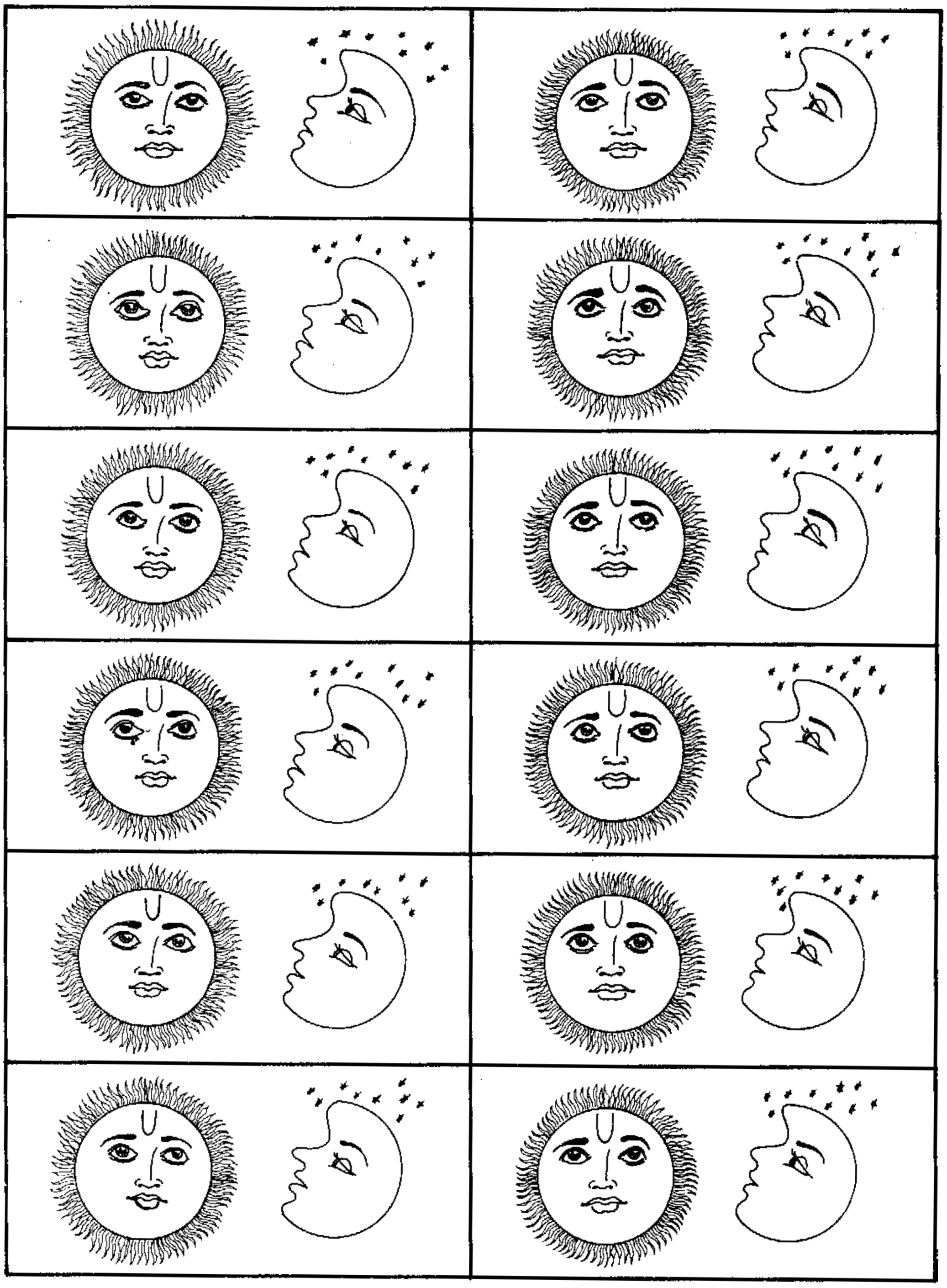


5. Place the small bead about 7 cm from the torch in line with the large bead. See the sharp shadow of it fall on the large bead.



6. Move the small bead away from the large bead and towards the torch. See how its shadow on the large bead grows smaller, less sharp and finally disappears.

You must do this activity in a darkened room or at night, with all the lights off except the torch light. Otherwise you will not be able to see the shadow.



4. THE VIEW FROM THE EARTH

One sequence in which the three eclipse players can line up is the sun—the earth—the moon. That is, the sun and the moon are in opposite directions as viewed from the earth. We know that whenever the sun and the moon are in opposite directions in the sky it is a bright full moon night. Have you ever seen a full moon rising? You can see the setting sun at the same time as the rising full moon. It is a marvellous sight. It clearly shows what we already know, that the sun and the moon are in opposite parts of the sky on a full moon night or *Purnima.*

During a full moon night, the moon continues to go around the earth and the earth around the sun. Naturally their shadows also race across space along with them! But the moon travels across the sky faster than the shadow of the earth and catches up with it from the west. What do you see from the earth? Something really very dramatic. A tiny slice of the eastern edge of the moon that was full until that instant appears missing! Slowly more and more of it disappears. What is happening? It is easy to guess. The shadow of the earth is slowly creeping over the face of the moon. No light from the sun falls on the parts of the moon temporarily. Since the moon has no light of its own, we can see no light coming from these parts. As the moon is covered by more and more of the shadow, less and less of the full moon is visible from the earth. From the earth, we are watching a lunar eclipse. What would one see from the moon?

Fig. 9 : Lunar eclipse sequence

The other order in which the three players can line up is the sun—the moon—the earth. In such a situation, when you are looking at the sun during the day you are also looking at the direction in which the moon is in the sky. Of course you cannot see the moon because the face of the moon that is turned towards the earth is not lighted by the sun. We know that this is the new moon or *Amavasya*.

According to the rules of the game, the moon must go around the earth and the earth must go round the sun along with their shadows. Suddenly this time, the shadow of the moon catches up with the earth and falls on the earth! But unlike the earth's shadow which is able to cover the whole of the moon, the moon's shadow covers only a small part of the earth. This shadow travels from the west to the east as the earth spins from the west to the east. If you happen to be on the path of the moon's shadow you will see that slice after slice of the sun disappears into darkness until the whole sun is covered. Then the drama repeats itself in reverse and the sun reappears as whole again. From the earth, we see a total solar eclipse. What does someone on the moon see!

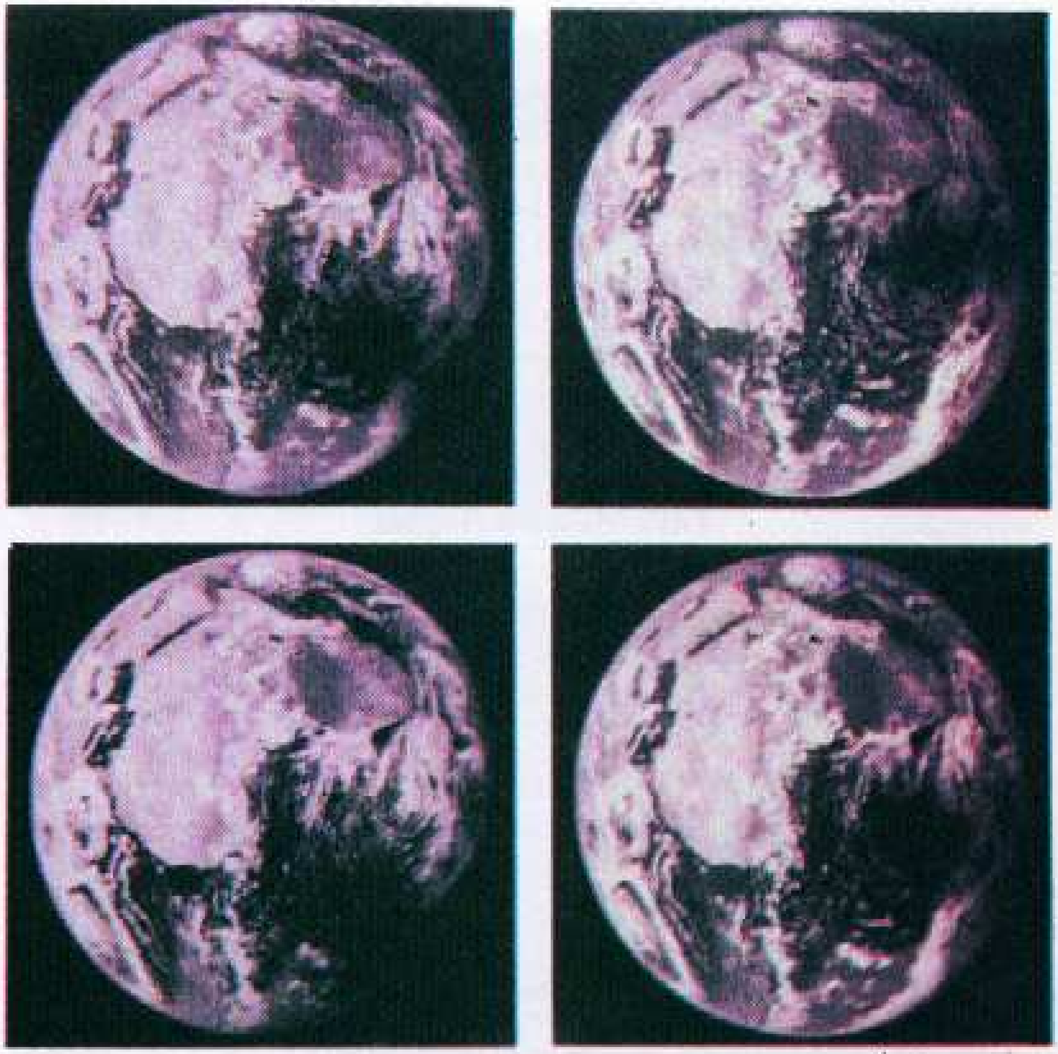


Fig. 10 : The travelling shadow of the moon—photograph by the weather satellite Meteosat during the total solar eclipse of June 30, 1992 over the south of Atlantic

It is easy to understand a large earth covering the small moon with its shadow. But how is the tiny moon able to hide the huge sun?

Angular Size

Whether one object can completely hide another depends not only on the sizes of the object but also on how far away each is from your eye. Both the real size and the distance from the eye are combined together as the angular size of the object.

Angular size = Real size/Distance

So a small object that is near, can have the same angular size as a large object that is far away. If an object has an angular size of 1 degree then it is at a distance 57.3 times its size from the viewer.

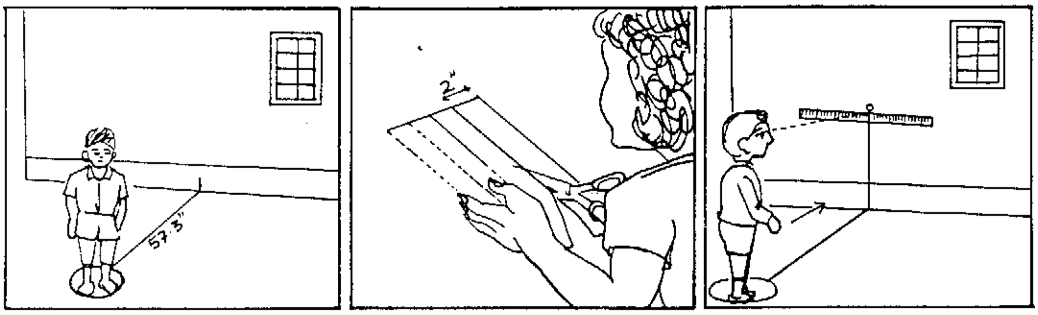
By a remarkable coincidence the sun is approximately 400 times larger than the moon and is also 400 times further away from the earth. So their angular sizes are nearly equal making it possible for the moon to completely hide the sun. Both are about half a degree in angular size. That is, the ratio of their distance from the earth to their size is about 115. In this activity you can find out how to measure angles using parts of your hand.

Let's Measure Angles

What you need

A sheet of paper
A 60 inch measuring tape
A pair of scissors, sticking tape, chalk

What to do



1. Mark a point at the bottom of a wall. Measure 57.3 inches on the floor from the point. Draw a circle to fit your feet at this distance.
2. Cut the sheet of paper into 2" wide-strips and join them to make a 20" long strip. Mark inches on the strip as shown.
3. Tape the strip on the wall at the level of your eye. Zero mark should be in line with the mark at the bottom of the wall.

Angular size = Real size/Distance

So a small object that is near, can have the same angular size as a large object that is far away. If an object has an angular size of 1 degree then it is at a distance 57.3 times its size from the viewer.

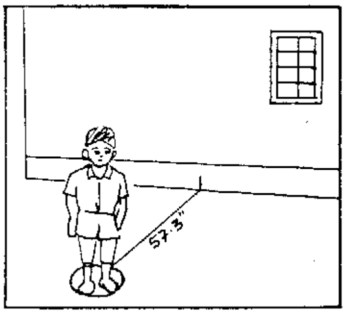
By a remarkable coincidence the sun is approximately 400 times larger than the moon and is also 400 times further away from the earth. So their angular sizes are nearly equal making it possible for the moon to completely hide the sun. Both are about half a degree in angular size. That is, the ratio of their distance from the earth to their size is about 115. In this activity you can find out how to measure angles using parts of your hand.

Let's Measure Angles

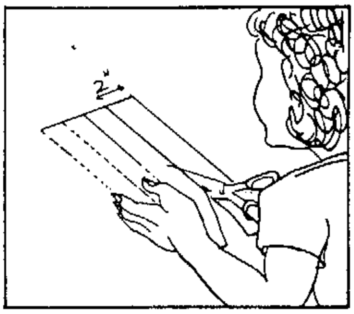
What you need

A sheet of paper
A 60 inch measuring tape
A pair of scissors, sticking tape, chalk

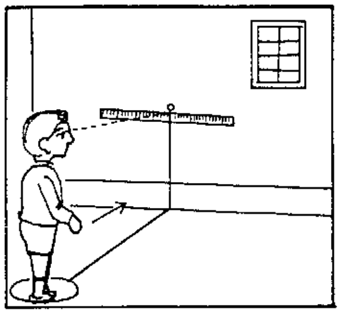
What to do



1. Mark a point at the bottom of a wall. Measure 57.3 inches on the floor from the point. Draw a circle to fit your feet at this distance.



2. Cut the sheet of paper into 2" wide-strips and join them to make a 20" long strip. Mark inches on the strip as shown.



3. Tape the strip on the wall at the level of your eye. Zero mark should be in line with the mark at the bottom of the wall.

5. ECLIPSE MYTHS

When scientists come across a new natural phenomenon today, they ask themselves, how does it happen, why does it happen? To answer these questions one of the techniques they use is to first make a model of the phenomenon. It can be a mathematical model or a physical model, based on what they already know.

Our human ancestors who saw eclipses must have asked the same questions. How does it happen? Why does it happen? And from these questions arose the first models of the phenomenon of eclipses—myths. Every ancient civilization constructed its own myth about eclipses. There is however one common thread; that the sun or the moon is being devoured by some evil being. This 'model' is easy to understand, as that is what is seen during an eclipse—parts of the sun or the moon gradually disappearing.

The earliest Indian myth on solar eclipse is found in the *Rig Veda*, a book composed between 1500 and 1200 B.C. In this myth a demon Svarbhanu pierces the sun with a darkness so complete that "all the worlds stood as if not knowing where they were." The sage Atri got back the sun who was hidden by darkness by means of the fourth brahmana incantation.

In later years we find another myth associated with eclipses. In a description given in the *Mahabharata*, an epic poem in Sanskrit, the gods and the demons are advised by Vishnu to churn the ocean for Amrit,

Fig. 11 : *Amrit Manthan*

the drink that will give immortality. When the pot of Amrit floats up, Vishnu does not want the demons to taste the Amrit and become immortal. He tricks them and distributes the Amrit only to the gods.

One smart demon, the snake-headed Rahu, however notices this. He disguises himself as a god and sneaks in between the sun and the moon, ready to receive the Amrit. But they quickly spot and report him to Vishnu just as he is about to taste the Amrit. Vishnu wastes no time and cuts off his head, but not before Rahu has taken a tiny sip! So Rahu's head becomes immortal and the rest of the body falls dead. Rahu has never forgotten the treachery of the sun and the moon. Even today he swallows the sun and the moon from time to time, causing eclipses!

By the first century A.D. Indian astronomers knew the mathematical rules for calculating eclipses. They however retained the earlier terminology in the scientific Hindu astronomy of those times. Rahu and Ketu (the bottom half of Rahu) are defined as the points in space at which planes of the orbit of the earth and the orbit of the moon intersect each other. As we shall see later, an eclipse can occur only when the moon is at one of these points. So Rahu is not a snake-headed demon but an important point in the celestial sphere.

Let's Match the Myths

What you need

Cards from the next page and scissors

What to do

Cut each card out individually. Place cards face down. Try to make the correct pair. Play with a partner.

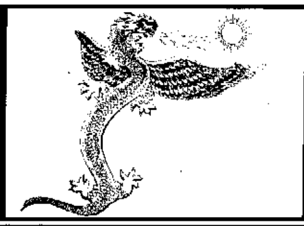
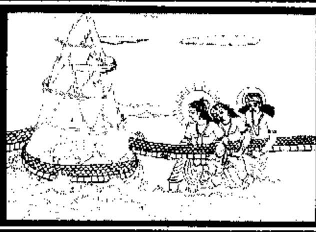
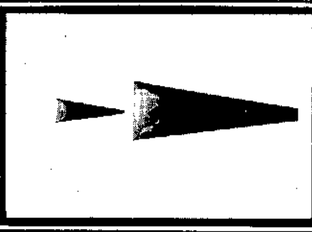
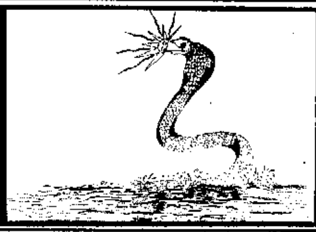
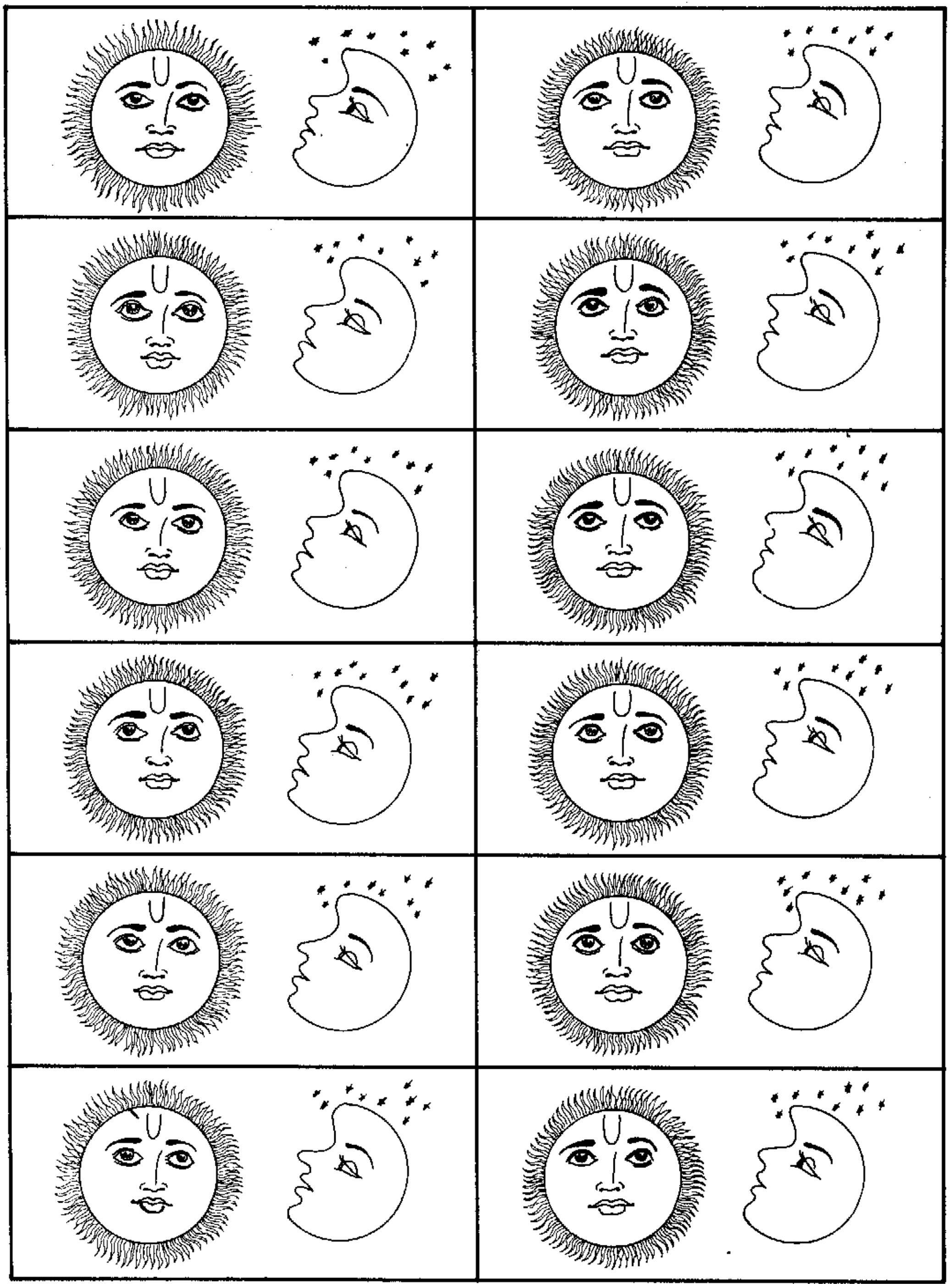
1. In the *Rig Veda* the demon Svarbhanu strikes down the sun. The sun is restored by prayers recited by sage Atri.	
2. In a Chinese myth a dragon swallows the sun. It is frightened away by the beating of drums.	
3. In Mexico the Mayan word for eclipse is *chibil kin* and literally means a "bite of the sun". The Mayan tablet called the Trocortesiano Codex of Madrid is a record of eclipses. Notice at the bottom left a snake about to devour the sun.	
4. In a later Indian myth, Rahu a demon sneaks in between the sun and the moon to receive a portion of *Amrit*.	
5. In the modern model, the shadow of the moon falls on the earth and the earth residents can see a total solar eclipse from a narrow region on the earth.	
6. In Africa, the eclipse myth tells us that a snake in the ocean grows and grows until it is too large to fit in there. It therefore ascends to the sky and swallows the sun. It is scared away by the beating of drums.	

Fig. 12 : Myths—a matching game



6. AS THE MOON FLASHES BY

In the game of eclipses that the sun, the moon and the earth play, once the moon hides the sun or the earth's shadow takes away the brilliance of a full moon, the game is over and the players are on their way for the next game, without even pausing for breath! Even though you the resident on the earth know their game, you are impressed and watch it with wonder while it lasts.

There are many variations in this game of eclipses. You already know two major ones, a lunar and a solar eclipse. There are different types within these two. Lunar eclipse can be partial or total depending upon whether the shadow of the earth catches the whole of the full moon or only part of it. In a total lunar eclipse the curved edge of the earth's shadow advances covering the moon fully at totality. Strangely the eclipsed moon is not totally dark! There is a faint red glow coming from it and the features are still visible on it.

Ancient Hindu astronomers had classified lunar eclipses according to their colour. Today, we know from where the eclipsed moon gets its reddish glow—from the earth! While the solid part of the earth cuts out the sun light completely the earth's atmosphere lets the red part of it through, scattering away the blue part. It also bends it so that it can fall on the eclipsed moon and light it up faintly. Evidently there are several side shows to the eclipse game!

On the other hand there are three kinds of solar eclipses—partial, annular or total. Of all these lunar and solar eclipses, a total solar eclipse

Fig. 13 : A total lunar eclipse

is the most spectacular. Imagine a fine sunny morning. The sky is clear blue. Somewhere to the west of the sun in the sky is lurking the new moon whose dark face you cannot see! The sun appears to move westwards, exactly as it does every day as the earth spins from west to east. The moon is not still either. Gravitation demands that it keeps going round the earth. So, as seen from the earth, the moon is slowly sneaking up towards the east unseen by any earth resident.

Then, at one instant, the eastern edge of the dark moon's disc just touches the western edge of the glowing sun. First contact! Then slice after slice of the sun surrenders to darkness, the boundary of darkness always being the arc of a circle. A strange creeping darkness falls on the landscape. Cool winds blow. Animals and birds think it is an early sunset! This goes on till only a tiny crescent of the sun is left. Waves of

Fig. 14 : Diamond ring—The sun sparkling through a lunar valley seconds before totality

light and dark ripples race across the landscape as though a million snakes have descended on the earth. Second contact! In that instant, a pink ring of fire frames the dark disc of the moon. A speck of the sun flashes from behind the jagged edge of the moon. It is like a most brilliant diamond, set in this ring of pink fire. Before you know it, a cool pearly light, stretching from around the dark moon, in long graceful streamers leaps into view. It is the most beautiful sight. This is the solar corona. A few minutes of utter tranquility wraps the land. As you look around you can see some bright stars and planets. Stars during day time! Then comes third contact. Another diamond, set at a different place in the pink ring flashes and the pearly light vanishes abruptly. The moon cannot stop itself. It continues eastwards, while the

sun continues on its apparent westward course to sunset. At fourth contact, the sun re-emerges from behind the moon in its old glowing self. Birds and animals think it is another day and rejoice. The game is over and the players are already off to the next one.

An annular solar eclipse is also an interesting sight. The angular size of the moon is smaller than that of the sun, when the earth is nearer than average to the sun and the moon is farther than average from the earth. The moon is unable to cover the entire disc of the sun and the sun shines through as a blazing ring.

Let's Match the Views

What you need

The cards from the next page and a pair of scissors

What to do

1. Cut out all the 12 cards.
2. Place them face down.
3. Match the pictures with the description. Play with a partner.

First contact—The western edge of the sun's disc and the eastern edge of the moon just appear to touch. In ancient Hindu astronomy this is known as *sparsha,* meaning, to touch. (fig. i)

Second contact—The eastern edges of the discs of the sun and the moon appear to touch. The pink chromosphere and the corona leap into view. Totality begins. (fig. ii)

Third contact—The western edges of the sun and the moon appear to touch each other. Totality ends. Chromosphere and the corona disappear. (fig. iii)

Fourth contact—The eastern edge of the sun's disc and the western edge of the moon's disc appear to touch. End of eclipse, *moksha* in Hindu astronomy. (fig. iv)

When the tip of the moon's shadow just reaches the earth we see an annular solar eclipse. *Annulus* in Latin means ring. An outer ring of the sun is still visible. (fig. v)

When the moon enters the earth's shadow a lunar eclipse is seen from the earth. The earth's atmosphere lets through some light giving it a reddish glow. (fig. vi)

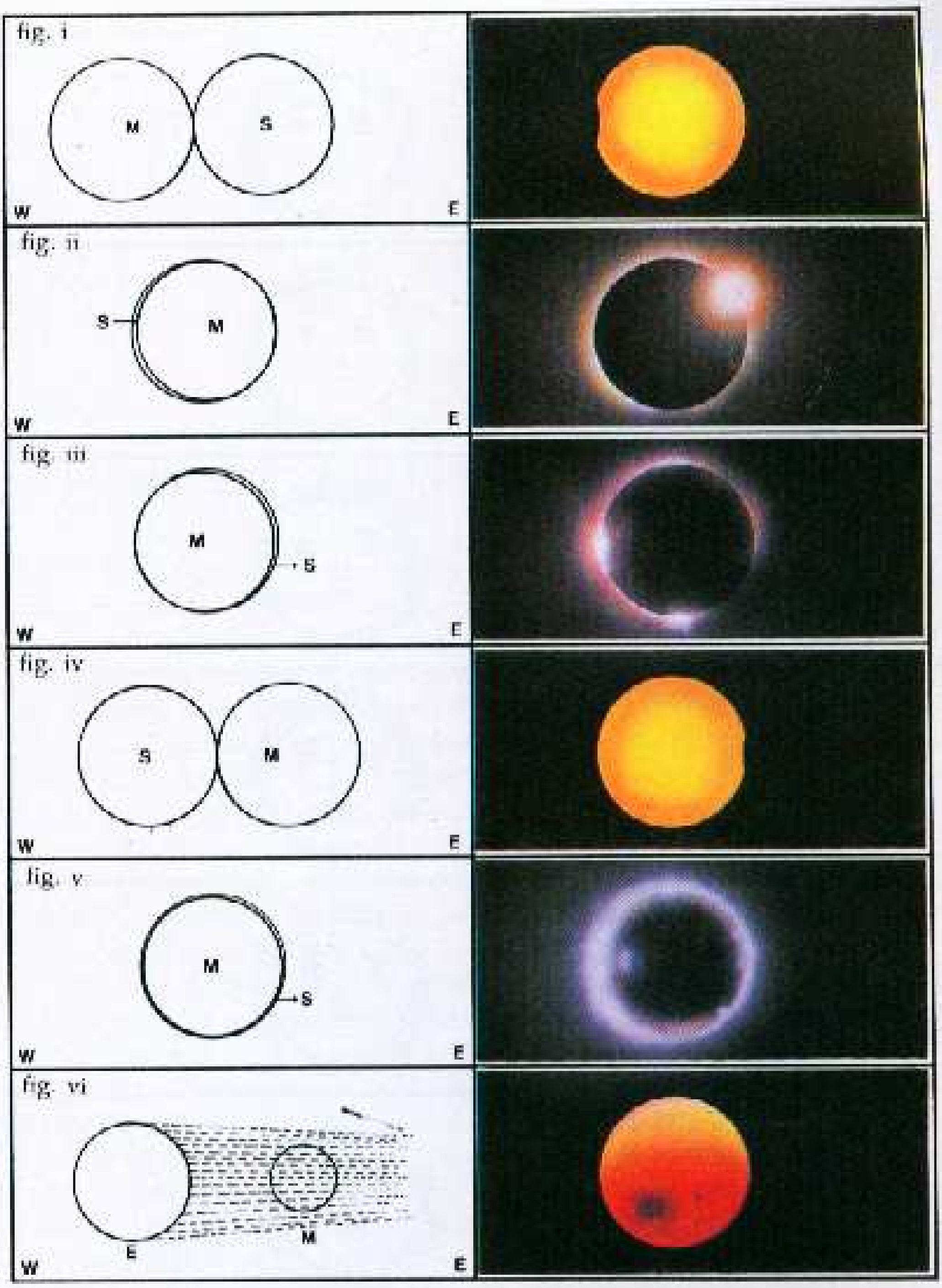
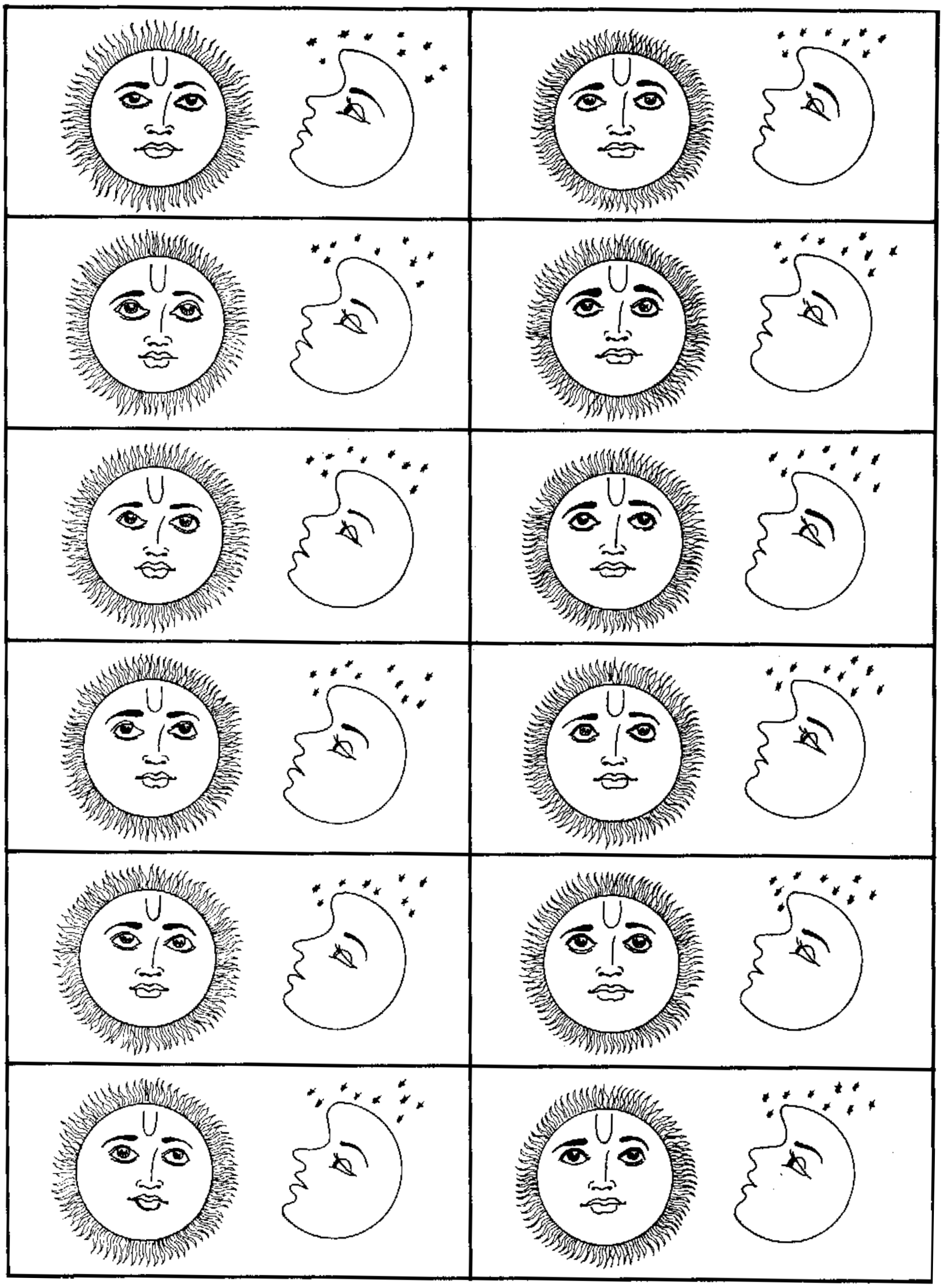


Fig. 15 : Eclipse stages—a matching game



7. THE ELECTRON CROWN THE SUN WEARS

Where do the pearly streamers that leap into view during a total solar eclipse come from? Why are they visible only when the moon fully covers the sun? These are the questions that scientists asked themselves in the early days. Before the invention of photography, most of them thought that these strangely beautiful features are caused by the eclipse, either in the atmosphere of the earth or on the moon. But photographs taken during a total solar eclipse in 1860 convinced them that these features really extend from the sun itself. We are not able to see these on any sunny day because they are as much as a million times fainter and are lost in the glare of the light from the solar disc. When the moon cuts out the sunlight during a total solar eclipse, these features suddenly become visible to the eye.

Today we know that the chromosphere (the pink ring of fire!) is a narrow layer of gas, some 2,000 km in extent. It is pink because it shines mainly in the red light emitted by the hydrogen atom. It is very patchy and so has the appearance of tongues of fire. The corona (the long pearly streamers) on the other hand, shines by scattering the light from the disc of the sun. But what scatters the light of the sun? The solar corona—literally solar crown—is visible only for a few minutes during a total solar eclipse. So astronomers had to study many eclipses before they could find out what the corona is made up of. Thus began a hundred years of eclipse chasing all around the globe. Astronomers braved long travel, difficult terrain, hostile locals and much more to

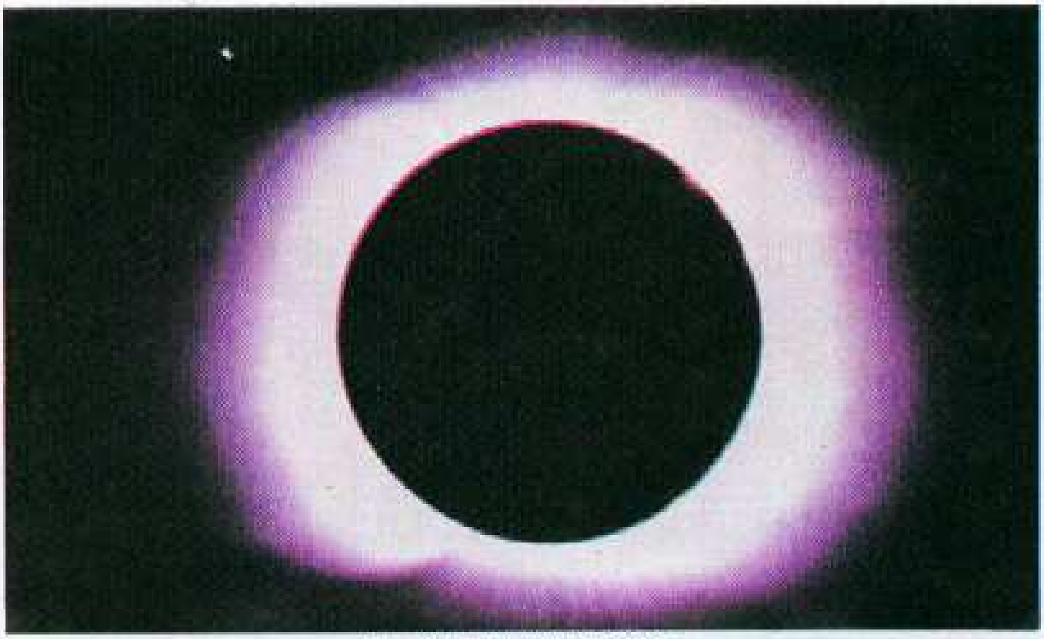


Fig. 16 : The solar corona

catch the corona on film and solve the mystery of its nature.

The corona consists of hot electrons, over a million degrees in temperature, stretching out to vast distances from the chromosphere. It is these electrons that scatter the light from the disc of the sun and acquire a pearly glow. The electrons are not distributed uniformly everywhere around the sun. Along a streamer there are more electrons and fewer elsewhere. So the streamers appear bright.

Although the corona is primarily made of electrons, scientists have found other elements in it as well. But at the very high temperatures present in the corona they are stripped of many of their electrons. That is, they are all highly ionised. Some of the ions of the iron atom found in the corona have as many as fifteen of their electrons removed. That is how the corona gets its generous supply of electrons! Despite the presence of ionised atoms and lots of electrons the corona is not a crowded place. In fact they are all so spread out that it is less crowded there than in the best vacuum created in a laboratory on the earth!

You can trace the brightest parts of the corona down to sunspots on the surface of the sun. It is well known that sunspots are places on the sun where the temperature on the surface is slightly lower than their surroundings. Surprisingly, over these very spots the corona is much

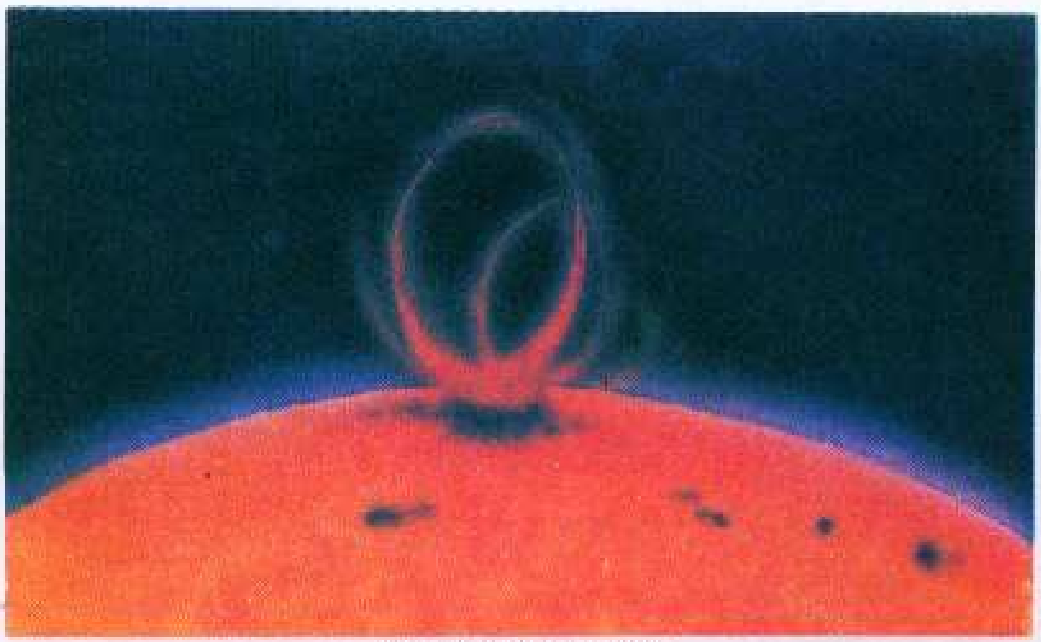


Fig. 17 : Coronal loops

hotter than its surroundings. Instead of a million degrees it can be an incredible 3 million degrees!

It is also well known that sunspots are associated with strong magnetic fields. If you look at some of the photographs of the graceful coronal streamers taken during a total solar eclipse, they appear to trace out the magnetic fields that are extending from the sunspots on the surface of the sun. This gives the clue, that the magnetic field that keeps the sunspot below cool is doing exactly the opposite in the corona! It is somehow taking part in heating the corona, thereby stripping the atoms and supplying the hot electrons. Isn't it amazing that nature works so hard to produce the beautiful coronal streamers. No wonder she doesn't allow us to see it every day, lest we take her disciplined hard work for granted!

Let's Find the Corona

The earliest method of recording images was, of course, by drawing them. For the last 150 years or so it has been possible to photograph them. In more recent times we can acquire digital images. The advantage of digital images is that, the analysis that usually follows an

observation is much more easy. Now-a-days even amateur astronomers are able to make digital images with their telescopes. In this activity you can trace the coronal steamers from a digital image of a total solar eclipse. Here each number is a measure of the brightness of the corona at that place. The larger the number, the brighter the corona.

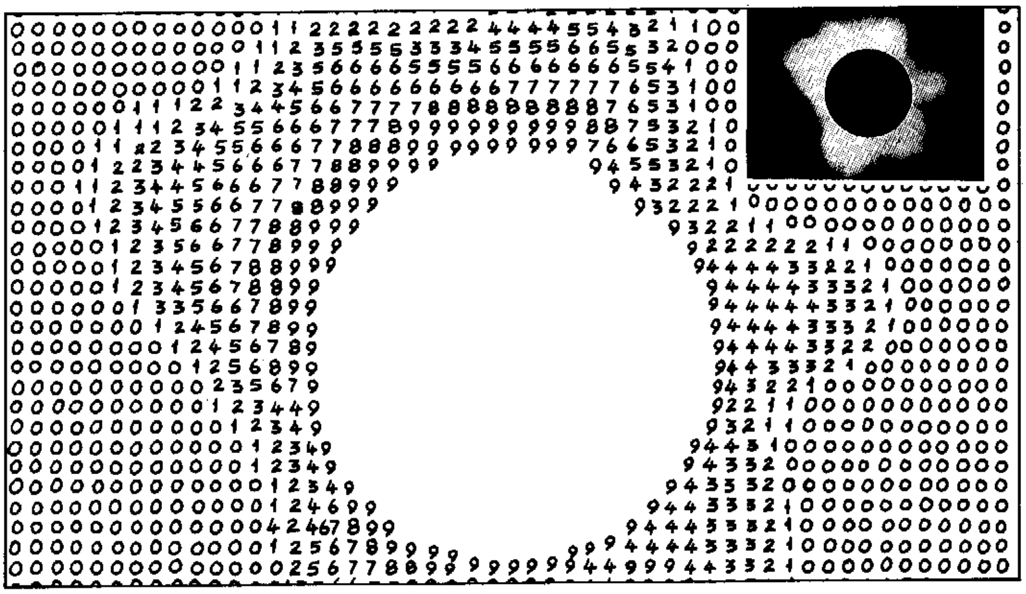


Fig. 18 : A digital image of the solar corona

What you need

The digital image from this page and a sharp pencil

What to do

1. Draw a curve to enclose all the numbers from 9 to 5 inside it. Similarly draw another curve to include the numbers 4 and 3, a third one to include the number 2 and one more to enclose the number 1. Lines enclosing one set of numbers must not cross that of another number. If the same number occurs far away, start a new curve to enclose the same. These lines are called contours.
2. Shade the region within a contour having the same number set with different degrees of grey. Make the regions with the largest number darkest.

Can you see the coronal streamers? You have now made a negative image of the corona! Compare it with the accompanying photograph.

8. SUNSPOT CYCLE AND THE CORONA

Let us set aside our exploration of the eclipse game and have a look at the face of the sun. The sun is so glaringly bright that you cannot look at it for longer than a few seconds directly. So let us use a telescope to do so. With a telescope you must NEVER look directly at the sun. You will become blind if you do so. You must project the image of the sun made by the telescope on a white card and examine that.

You will see that the disc of the sun does not have a smooth appearance. It looks grainy. You may also see that there are tiny dark spots on the disc. These are the sunspots. When Galileo saw them for the first time using his telescope in 1610, he could not believe his eyes! But when he saw them day after day he knew that they were certainly real and on the face of the sun.

Tiny as they look in a projected image of the sun, some of these dark spots could hold a whole earth and several moons! They look dark because they are cooler than their surroundings. Even this 'cool' place on the sun's surface may be at a temperature of about 4,500 degrees celsius! When large images are examined, the sunspots show an umbra and a penumbra like the shadows we played with! Also, very often, the spots appear in pairs. Accurate daily records of the sunspots, kept over several years show that their number and size increase and decrease in a cycle of approximately 11 years. This is the famous sunspot cycle, one more rhythm game that nature plays.

George Ellery Hale, an American astronomer, was fascinated by

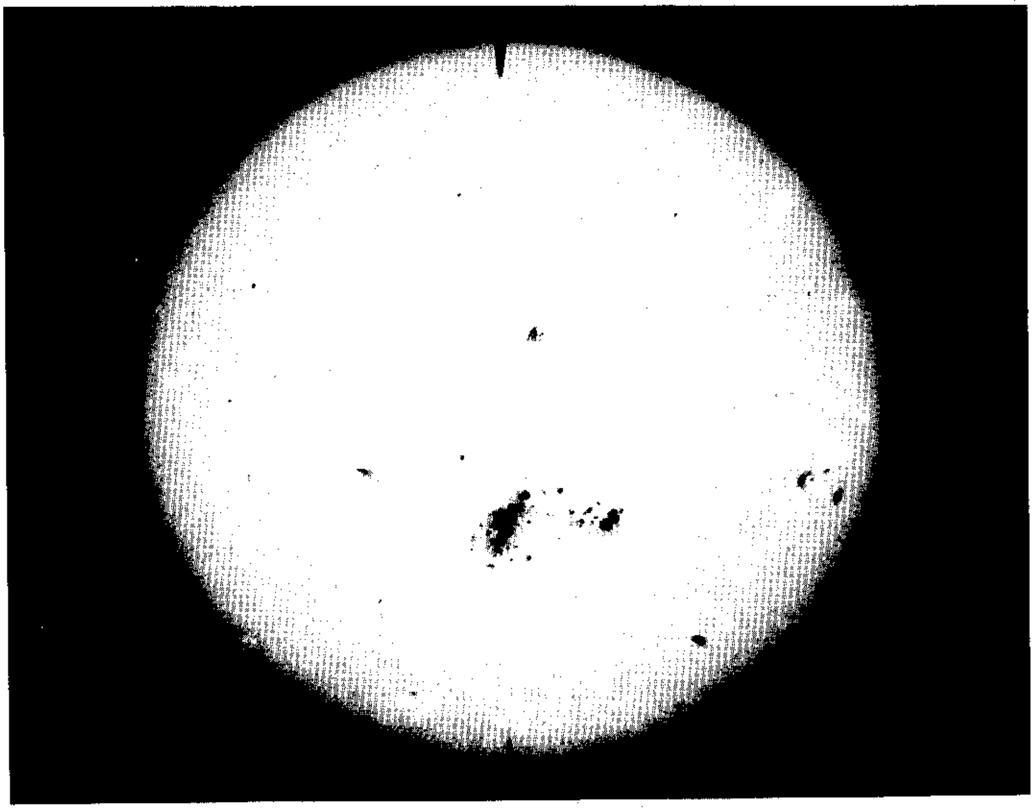


Fig. 19 : The solar disc with sunspots taken in white light

sunspots. He was not satisfied with seeing a telescopic projection of the sun in white light. He wanted to examine sunspots more critically. He built an instrument that could select out only the red light of the hydrogen atom and viewed the spots in that light. Around a pair of spots he saw a pattern of dark and bright features that resembled the way iron filings arrange themselves around a magnet! This suggested to him that sunspots had some sort of magnetic field around them. One spot appeared to be the north magnetic pole and the other the south. He tested this idea at once, by looking at the spectrum of the light that came from the sunspots. Sure enough, they carried the signature of a magnetic field. He found that the strength of the field is enormous, more than a thousand times the magnetic field of the earth!

Modern studies of the sun confirm what Hale found. They show that the regular changes in the magnetic fields on the sun are responsible for the sunspot cycle and many dramatic things that happen on

the sun. Some of them are so powerful that they affect us here, on the earth.

One of the results of the changing magnetic field is the appearance of the corona. The shape and brightness of the corona are not the same during every solar eclipse. Sometimes its brightness is more or less uniform around the disc and at others it is very asymmetric, shooting out long streamers in a few directions and none at all in the others. After many years of observation it was found that the brightness and shape of the solar corona was closely related to the sunspot cycle. Every 11 years the sunspot number reaches a maximum. The brightness of the corona also has the same cycle of increase and decrease! A corona seen during a sunspot maximum is bright and symmetric. During a sunspot minimum, on the other hand, the corona is fainter but displays long streamers. It is this varying appearance of the corona that gave a clue to as to how it is connected to the usually visible surface of the sun.

During a sunspot maximum, there are many strong magnetic fields emerging out of the many sunspots that dot the face of the sun. The hot electrons that travel along these fields are well spread over all of the

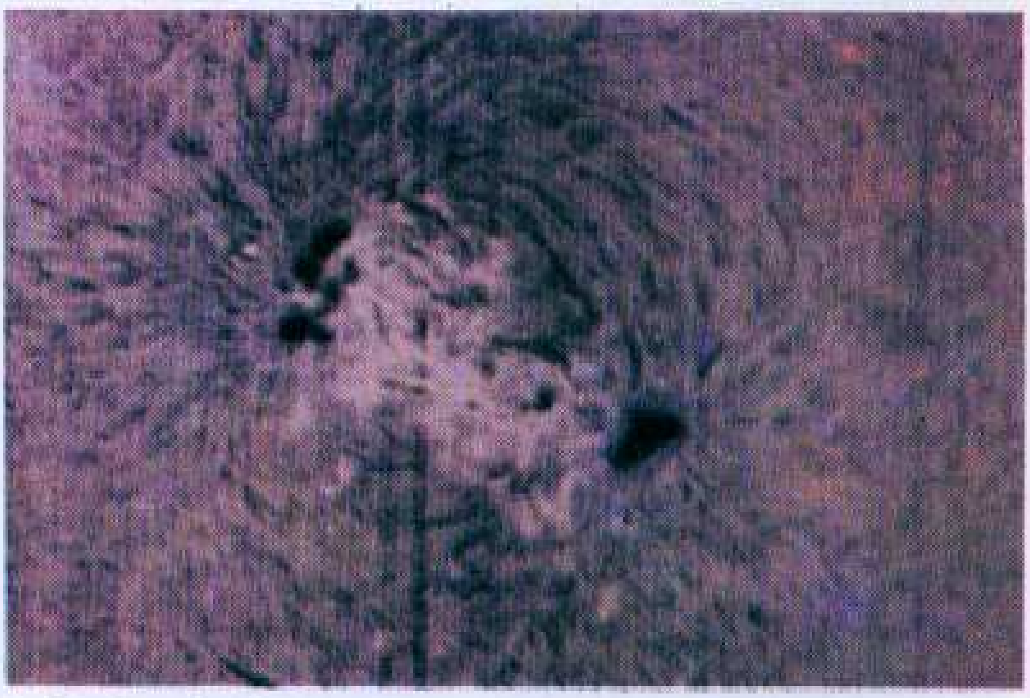


Fig. 20 : The solar disc taken in the red light of hydrogen. Notice how the matter is arranged around the sunspot

visible sphere of the sun. They are also confined close to it, as the strong fields that emerge out, curve back to the sphere quickly. This makes the corona appear bright and symmetric during a sunspot maximum. During a sunspot minimum there are much fewer sunspots and fewer fields. So, faint but long coronal streamers appear.

Let's Match the Coronal Views

In this activity you can match the views of coronal photographs taken during solar eclipses between 1900 and 1965.

What you need

The photographs and annual sunspot numbers on the next page
A pair of scissors

What to do

1. Cut out the corona and sunspot number cards.
2. Spread the cards face down.
3. Match the pictures with annual sunspot numbers. Play with a partner.

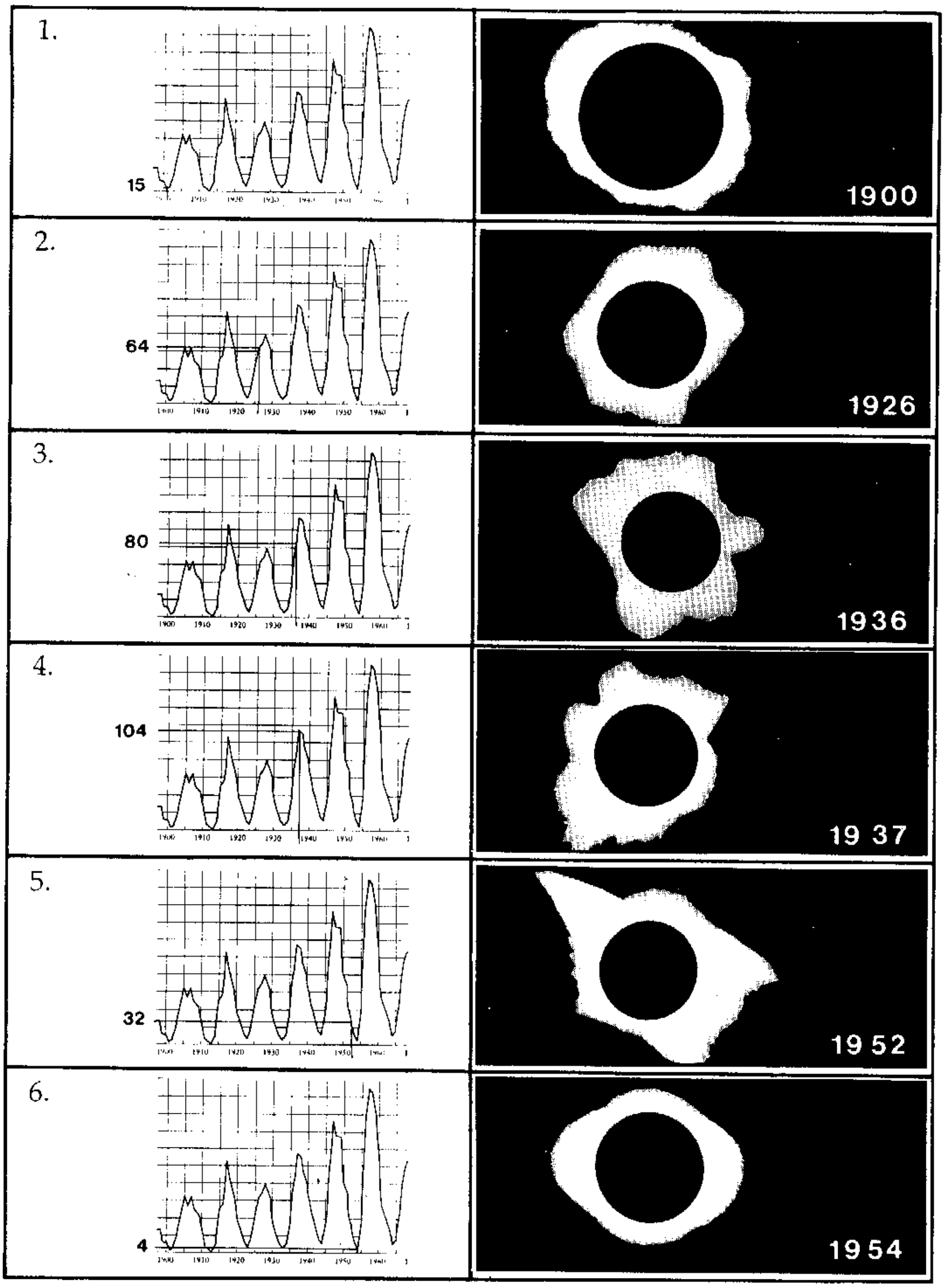
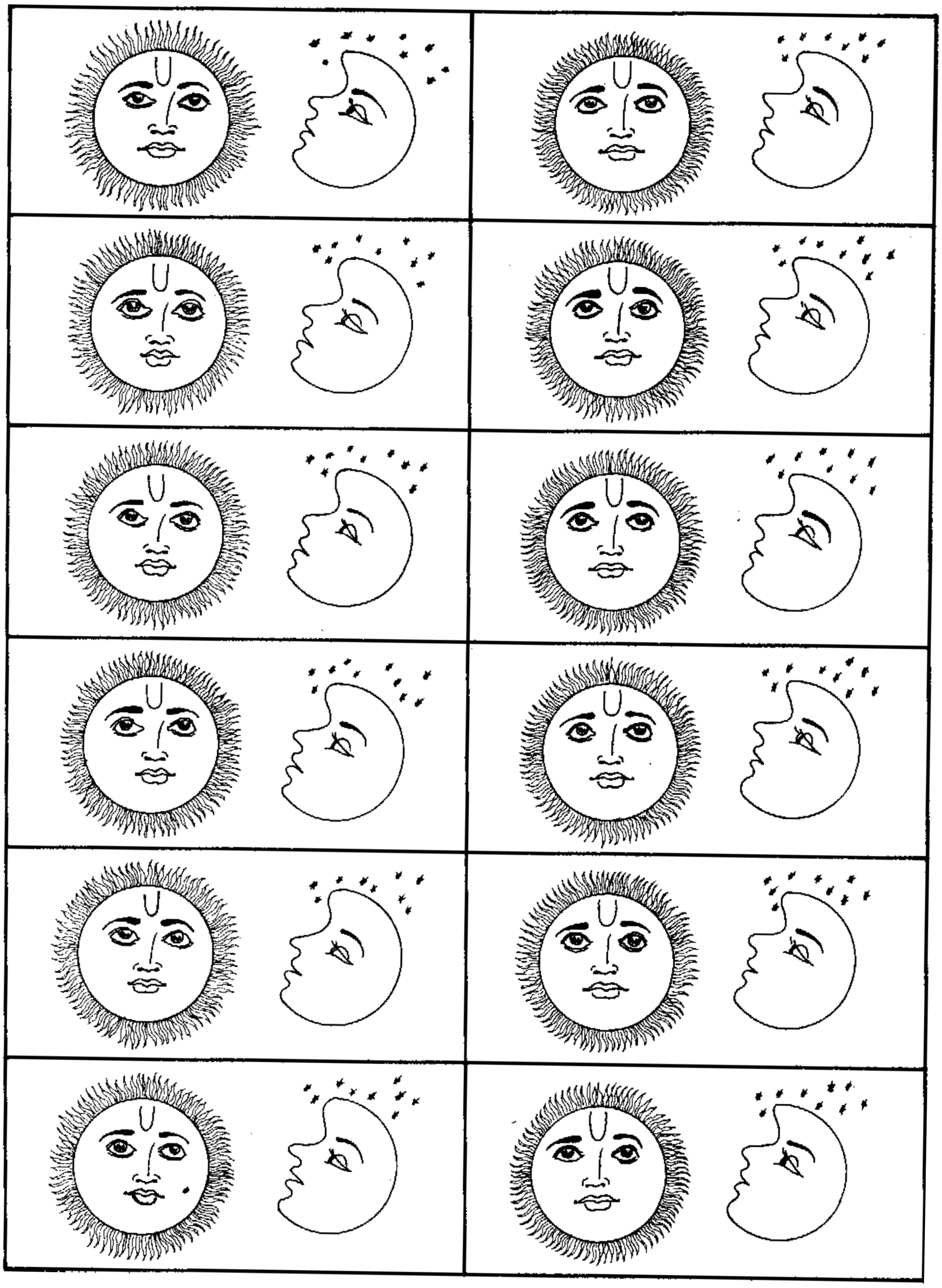


Fig. 21 : Solar activity and the solar corona—a matching game



9. THE FACE OF THE MOON

From here on the earth we can see with our naked eyes a 'rabbit' or an 'old man' on the moon. A telescope improves our vision and we trace mountains, plains and craters and map the moon. For 20 years from 1959 onwards spacecraft went round the moon and sent photographs that could see down to 10 m. The moon may become home to at least some adventurous humans in the 21st century. We must really know everything we can about the moon, before we depart on our moon trek! The eclipse game provides an opportunity to improve our knowledge of the moon's face.

The terrain of the moon is far from being smooth. Hills, plains and valleys are as common on the moon as they are on the earth. When seen in projection, these give the edge of the moon's disc a jagged appearance. As the moon's disc slides in front of the sun's disc, if there is a protruding mountain on the eastern edge of the moon, it will touch the western edge of the sun first before the time predicted for a smooth edge! By timing the instant of this contact it is possible to estimate by how much the mountain is protruding and so we can find the height of the mountain. The depth of a valley can be found by similarly, noting the delay in first contact. Since a different location on the edge of the moon makes first contact at different eclipses we can cover a variety of mountains and valleys on the moon.

Similarly, the sun flashes like a diamond through the valleys on the moon. Noting the times at which a diamond ring appears, before the

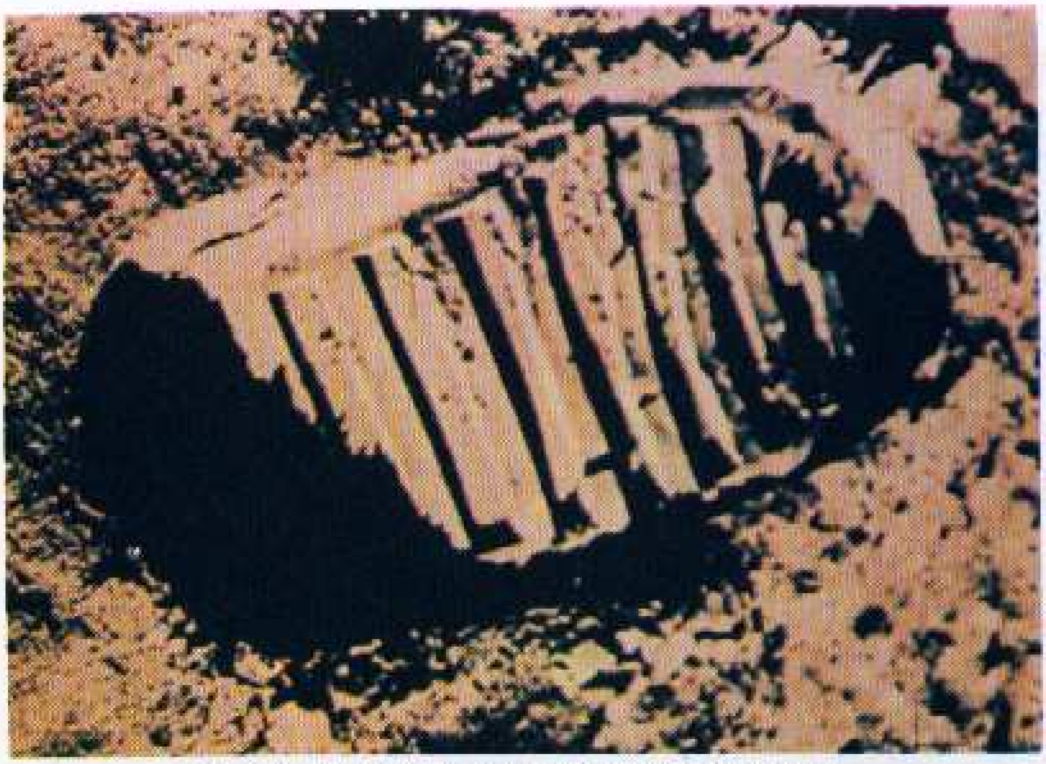


Fig. 22 : The foot print of an astronaut on the moon

second contact and after a third contact, allows us to measure the depth of these valleys on the moon. The method can be very accurate, as time measurements can be made very accurately.

Let's Draw the Moon's Face

The edge of the moon is not perfectly circular because the surface of the moon is not a regular and smooth surface. The features that are at the edge naturally give it a jagged appearance. There is another reason for this appearance. Very tall features that are not actually at the visible edge are projected against the disc. If they are sufficiently close to the edge they appear to stick out beyond the edge adding to the irregular appearance of the edge.

What you need

The drawings of the moon and its mountains on the opposite page
A pair of scissors, glue, pencil and a ruler

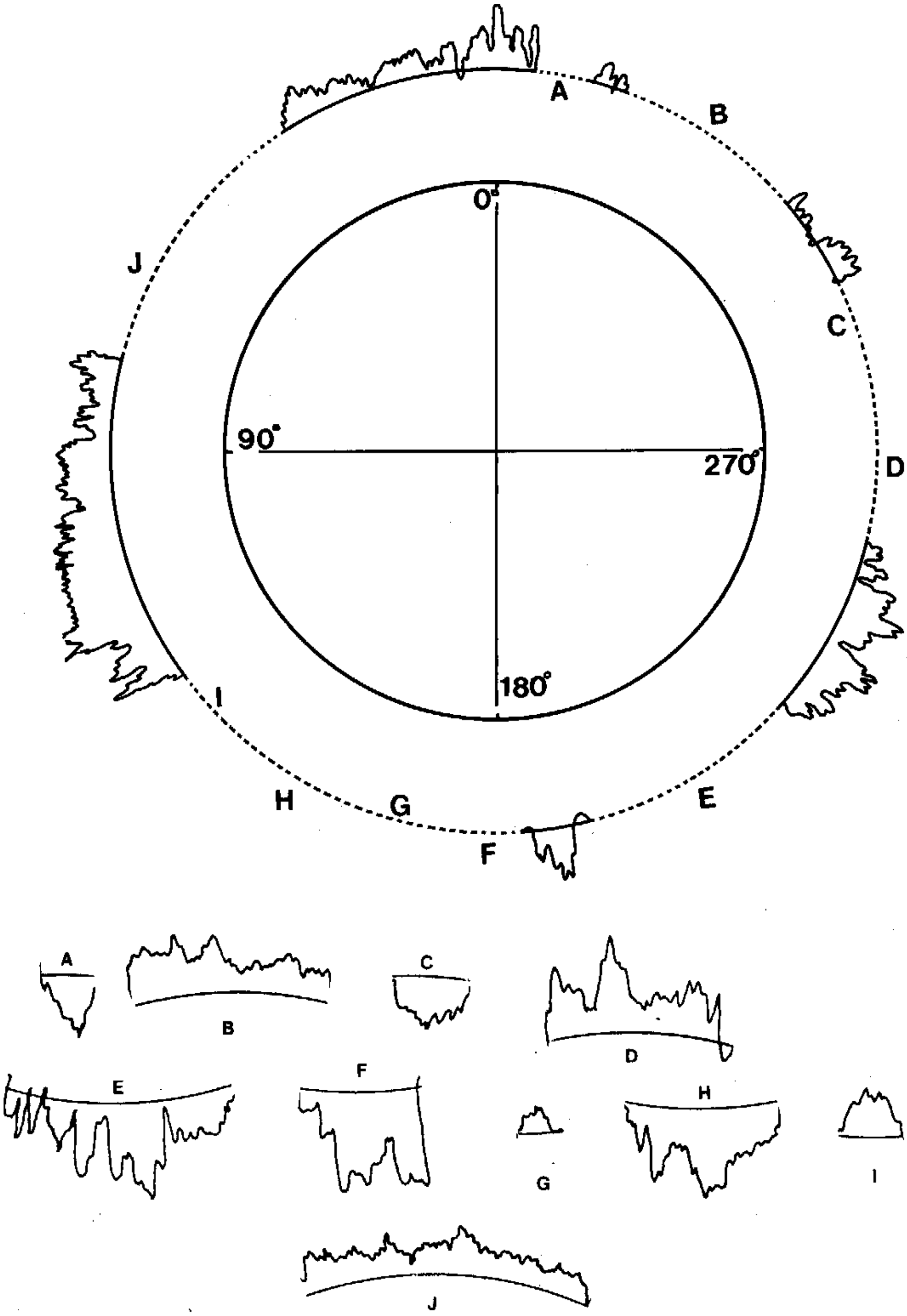
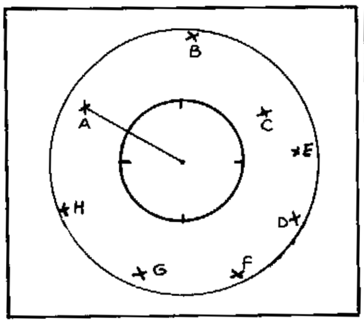
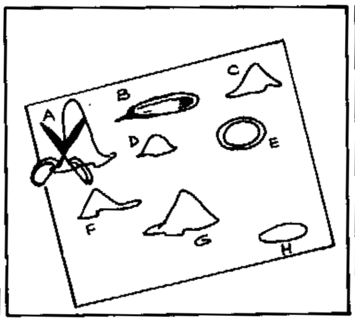


Fig. 23 : Moon outline

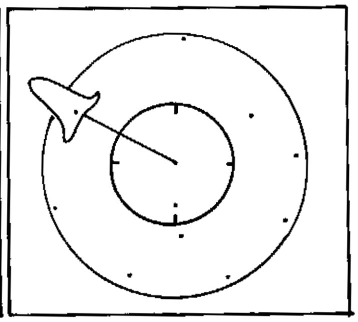
What to do



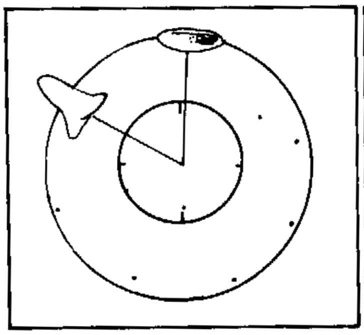
1. Join the point A to the centre of the outline of the moon.



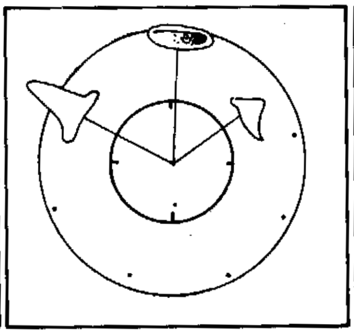
2. Cut out crater A.



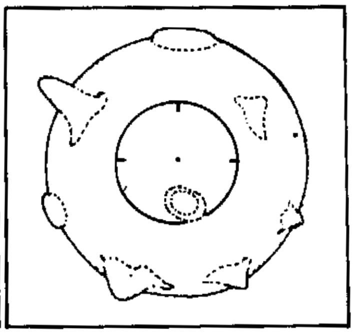
3. Stick crater A to the outline at the point marked A so that the circle drawn below it fits the moon outline circle.



4. Cut out mountain B. Place at B on the moon outline to complete the circle.



5. Repeat for all mountains and craters.



6. Now join the outline made by the mountains and craters on the edge.

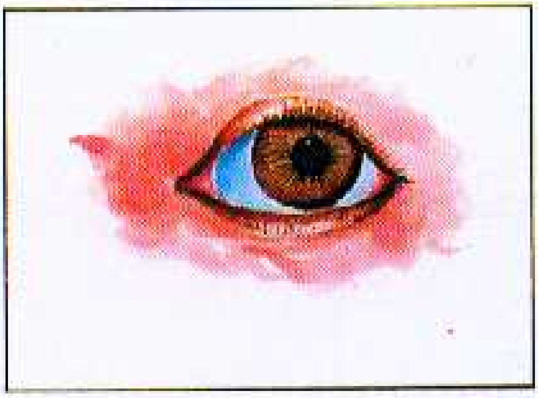
You have now constructed a Watt's profile of the face of the moon. This is the face that covers the sun. You can easily guess where you could see a diamond ring flash at the second and third contacts!

10. EYE INJURY DURING A SOLAR ECLIPSE

Ninety nine per cent of the sun's energy that reaches the earth's surface is in the form of heat and light radiation. It is no accident that the eyes of the creatures on the earth are sensitive to heat or light. They have evolved over billions of years to function that way.

The human eye, a delicate and complex organ, is sensitive to light radiation. It is designed to function over a wide range of light levels, the iris in front of the pupil contracting at high levels and opening out at low light levels—a technique used in modern cameras. The light collected by the eye is focussed on a screen called the retina. The sensitive tissues of the retina can be damaged if too much radiation falls on it. Watering and pain, are initial warnings that too much radiation has entered your eye. When still more radiation enters the eye the retinal cells burn and a permanent blind area results. A damage of this kind is caused both by the light (visible) and the heat (infra red) radiation. On a clear day if you look at the sun longer than 30 seconds with your eyes wide open, the damage will occur. But our eye closes automatically and usually we never look for this length of time as it is extremely painful to do so.

Much lesser amounts of radiation can also produce injury to the eye. This is caused by just a 2 degree increase in the temperature of the cells of the retina over the normal body temperature of 37 degree celsius. This damage is caused by the ultraviolet part of sun's radiation as well as the infra-red part. The damage may be temporary or permanent. That is why gazing at the sun for longer than a few seconds is always dangerous.



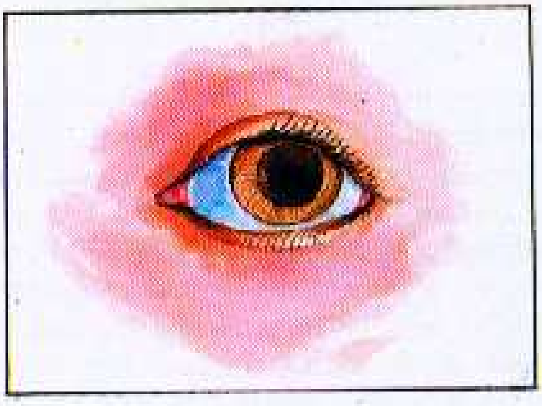


Fig. 24 : The human eye—notice how the pupil below, at a low light level, is open widely as compared to the pupil above

Viewing a solar eclipse whether partial or total, incorrectly, causes eye injury not because harmful rays are emitted at that time, but simply because people are tempted to stare at the partially eclipsed sun and it is easy to stare at a dimmed sun. It is completely safe to view the totally eclipsed sun directly. However, the highest possibility of eye injury is immediately after the totality ends. At that time, because of the low light level at totality, the iris is fully open. As the moon suddenly exposes the full brightness of the sun's edge, the wide open iris allows a lot of the heat and light radiation to enter, leading to injury. *A careful reading of the next chapter will enable you to enjoy a solar eclipse safely.*

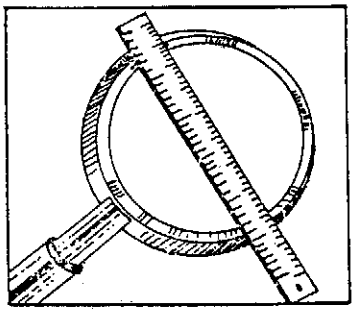
It is perfectly safe to view a lunar eclipse with the naked eye at all times.

Let's Test the Sun's Radiation

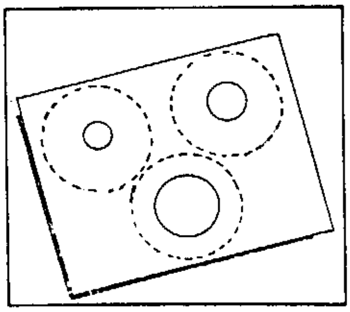
What you need

One magnifying glass
One white card, 10 cm by 10 cm
Sticking tape, pieces of newspaper, a pair of scissors, a watch

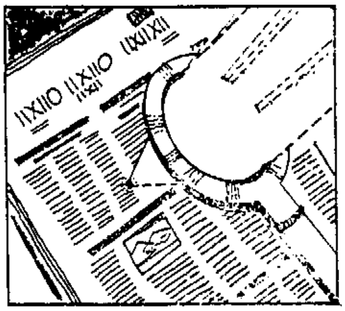
What to do



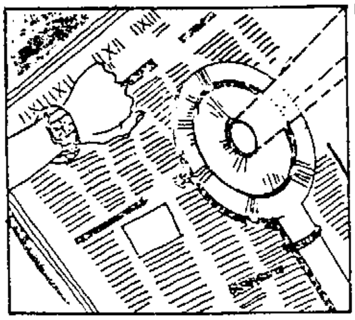
1. Measure the diameter of the lens of the magnifying glass.



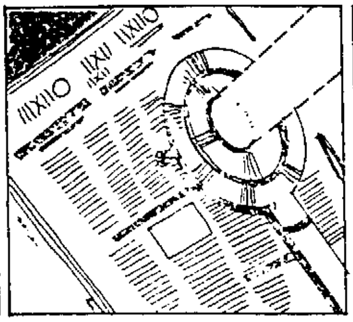
2. Cut out three circles of the same diameter as the lens from the white card. Cut out different-sized holes (in each of the circles).



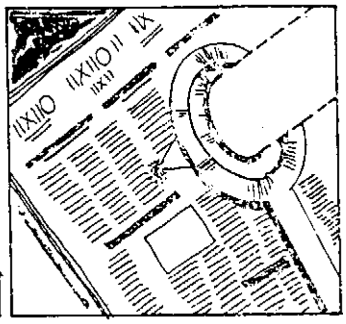
3. Hold lens over newspaper piece so that the image of the sun is brightest. Note the time.



4. Note time again when the paper starts burning (important: you must hold the lens steadily so that the brightest image of the sun falls on the same spot of the paper).



5. Repeat by taping white circles with different sized holes over the lens.



6. Note the time it takes to burn the paper, each time.

See how quickly the paper burns! Do not let this happen to your retina.

11. VIEW THE ECLIPSE SAFELY

It is during the partial phase of a solar eclipse that most eye injuries are likely to occur. Listed below are methods by which you can watch the progress of a solar eclipse safely. The same instructions would apply to all solar eclipses whether partial, annular or total.

Projection Methods

Make a 5 mm hole on a white card, with a paper punch. Tape this hole on a window facing east/southeast. During the morning hours a small image of the sun will be formed on the opposite wall. Darken the room as much possible for good contrast. You can watch the progress of an eclipse on this image. Larger the distance to the wall, larger will be the image of the sun. But it will also make the image fainter.

A brighter image can be obtained by taping the hole on a small pocket mirror. Position the mirror in the window to reflect the image of the sun on the wall or ceiling. The mirror will have to be adjusted from time to time to track the sun as it travels across the sky. Practice a few days before the eclipse to get it just right. No one should look at the sun in the mirror.

Very young children can wear a straw hat and sit with their backs to the sun. An image of the sun will form through the holes in the weaving and fall on the ground. The progress of the eclipse can be shown to them on this image. You can punch out a larger hole in the rim of the hat for a larger image, but do take permission from your mother before you do so!

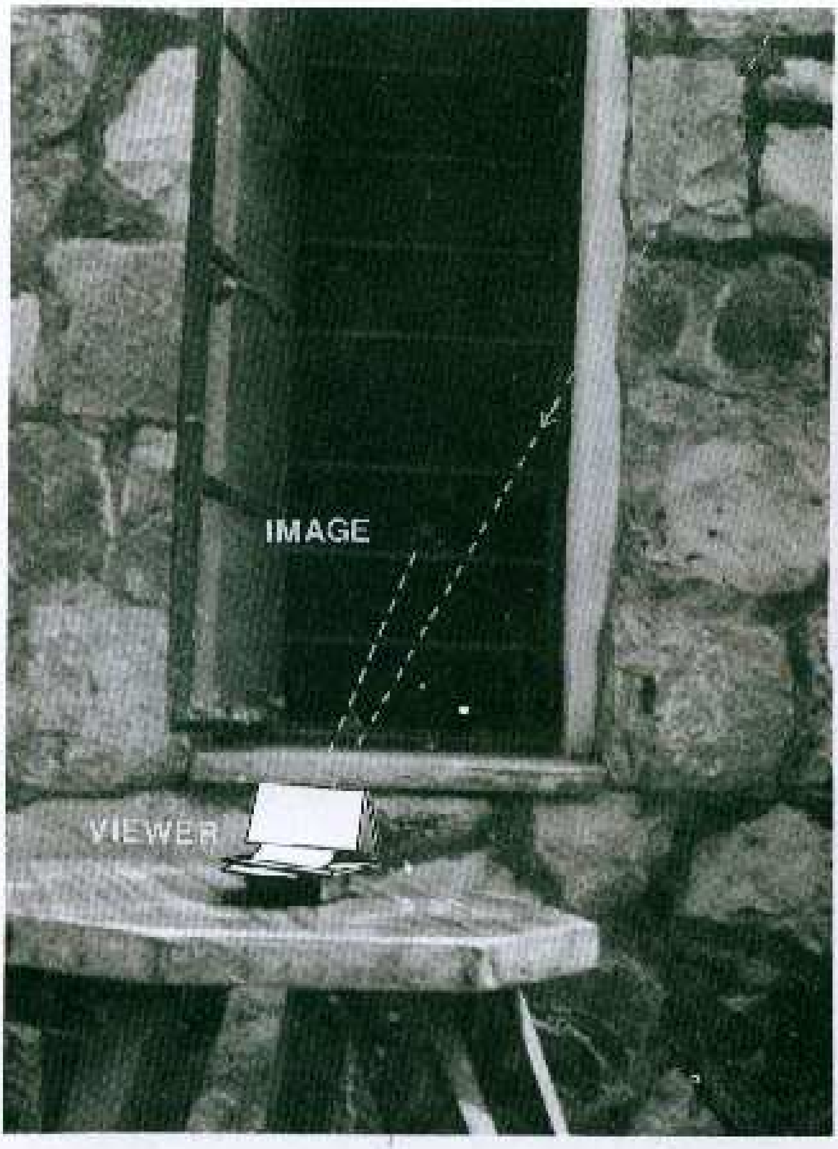


Fig. 25 : Image projection

Reflection Methods

Experiments have shown that viewing the sun reflected by coloured water (mixed with turmeric, cowdung etc.) in a shallow dish, for longer than 10 seconds causes watering of the eye. Since different people have different tolerances, this method is best avoided.

Direct Viewing Methods

Welders glasses no. 14 are safe, but many available in the market are not numbered and are spurious and can be unsafe.

6/7 layers of Garware RS- 20 sun control film held tightly together is safe as it allows only 1 out of 100, 000 parts of both the heat and the light radiation of the normal sun. Make sure that the number of layers is correct and that it covers your entire eye.

If you own a telescope or binoculars, project the image through the eye piece on a screen and watch the eclipse.

Do not use

Over exposed photographic/x-ray film

Over exposed colour film

Smoked glasses

Neutral density gelatin filters

The total phase of a solar eclipse can be viewed with the naked eye completely safely.

You can monitor the partial phase of the eclipse by the projection method. As soon as totality begins, you can view the same directly. You must stop looking directly as soon as the totality ends. Please check the length of totality for your location and count seconds mentally as you enjoy the corona. It takes one second to say 'one steam engine'!

Let's Make an Eclipse Viewer

What you need

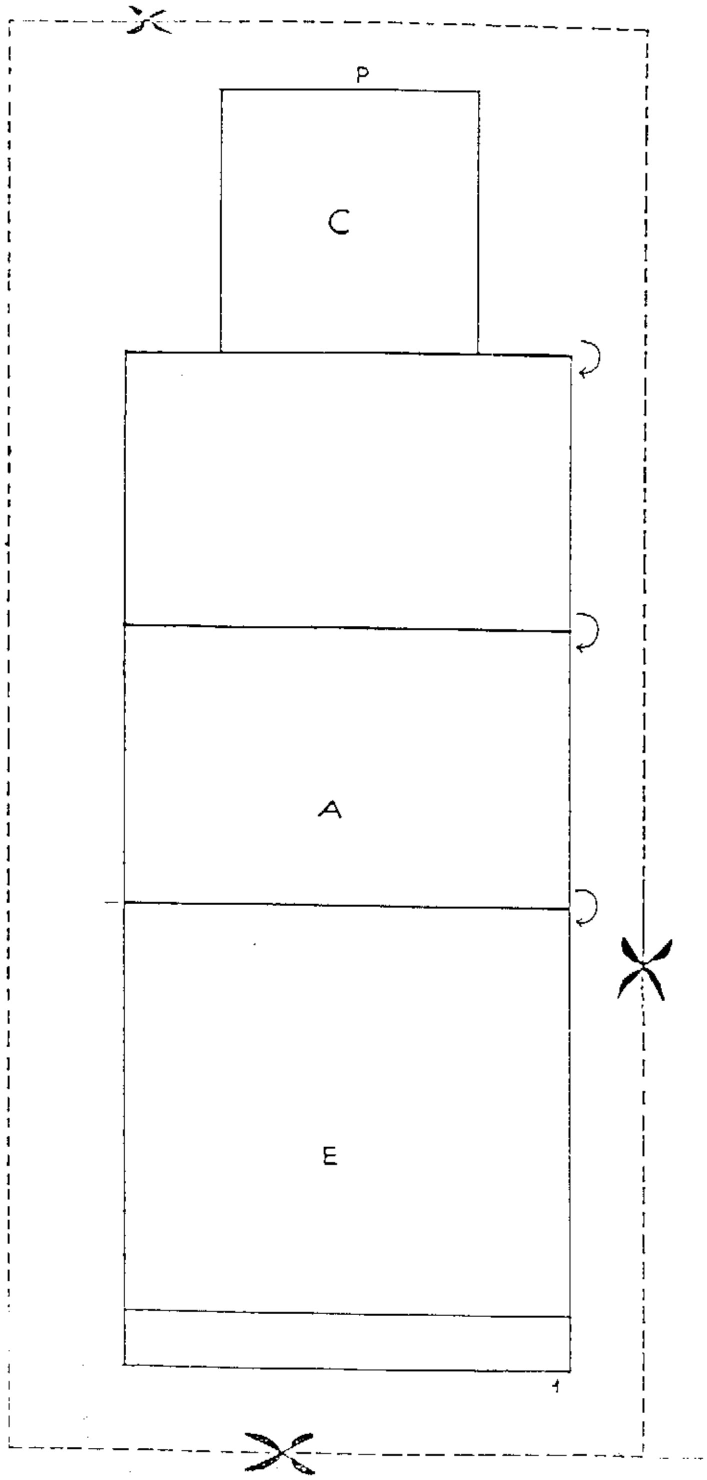
The pattern on the opposite page

Stiff card, the size of the page

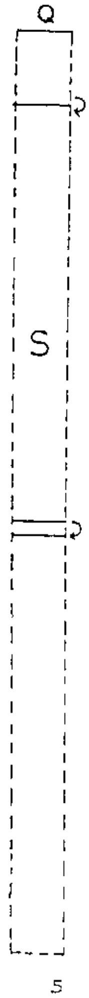
An empty match box, a small mirror piece, 1cm by 1 cm

Glue, blade, sticking tape, drawing pin/common pin

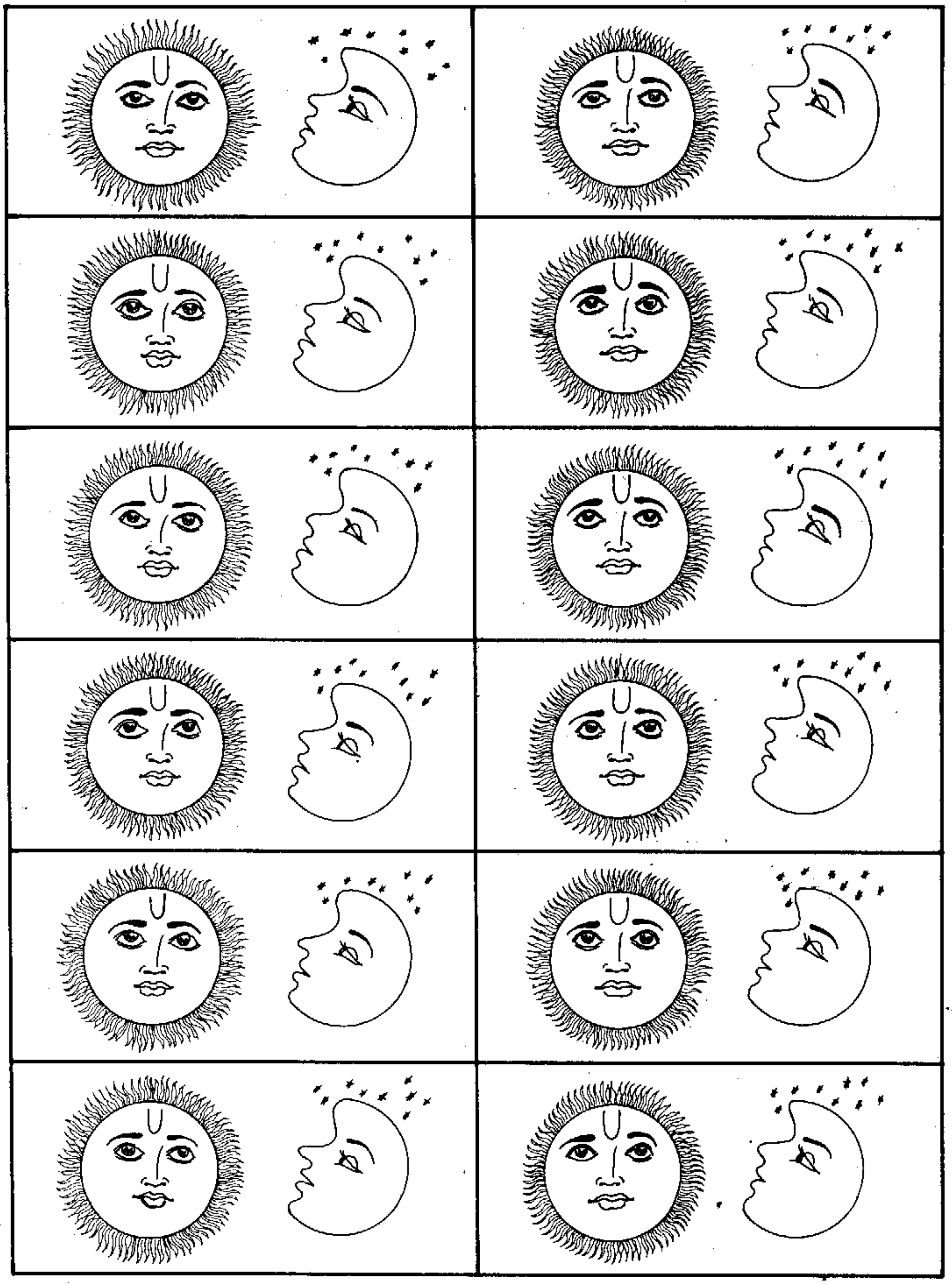
What to do

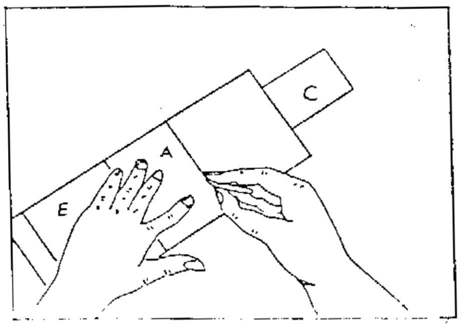


1. Cut the pattern and paste on

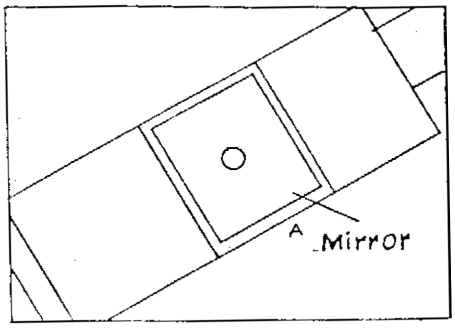


2. Cut out sleeve S.

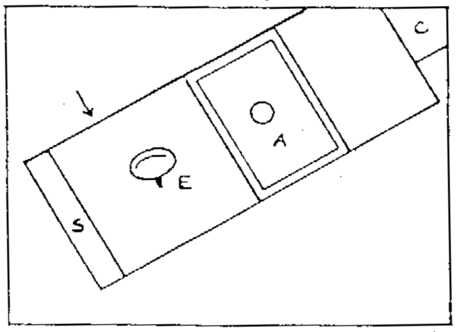




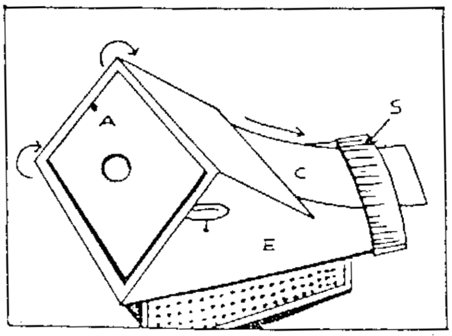
3. Make a shallow slit along dotted lines with blade. Do not cut through. Fold as shown.



4. Paste mirror at the centre of A. Tape a 1 cm by 1 cm white paper with a 5 mm hole in the centre on mirror.



5. Insert drawing pin/common pin through E and the face of the match box. Check if the top part rotates smoothly.



6. Fold sleave S and glue to the viewer as shown. Insert C into the sleeve. Pull C back and forth to see if you can smoothly change the slant of the mirror.

Your eclipse viewer is now ready for testing. Place the viewer on a window ledge. Use a stool of the height of the window if your window has no ledge. Adjust the slant mirror to reflect the image horizontally. Now rotate viewer about the drawing pin to send the light inside the room. You can view the image of the sun on the opposite wall. Change the slant and the rotation angle whenever the image moves out of view. You can draw the phases of the eclipse in this way and record the time of each drawing.

12. BE AN ECLIPSE CHASER!

Once you have seen an eclipse, especially a total solar eclipse, you catch the eclipse fever! Wherever and whenever an eclipse occurs anywhere in the world you will want to see it. If you are young enough you might also want to travel to the moon to catch a different perspective of this eclipse game altogether. But to do this you or somebody out there must be able to predict an eclipse.

That appears simple. We already know the conditions for an eclipse. The sun, the moon and the earth have to line up. If the distances are right, the shadow of the moon might fall on the earth or vice versa and you have an eclipse to enjoy. A lunar eclipse does not occur at every full moon or a solar eclipse at every new moon. That means that the lining up of the three players does not occur twice a month. Why?

One factor that prevents the three from lining up twice a month, is the way the moon moves around the earth. This path is not in the same plane as the path of the earth around the sun. It is tilted at about 5 degrees and intersects the plane in which the earth moves at two points. These are called nodes, the *Rahu* and *Ketu* of Hindu astronomy. It is clear that the three can line up only if the moon is at the point of intersection of the two planes when it is either full or new moon. This tilt therefore, adds one more condition for the eclipse to happen. If this condition is not fulfilled there is no eclipse. So eclipses do not happen twice in a month.

Twice in a year, the line joining the two nodes points in the direction of the sun. Only during these times can the full or new moon be near a node. These periods are called eclipse seasons. It appears therefore that eclipses can be predicted to take place on the full and new moon days of the eclipse season. But remember gravitation? It makes both the sun and the earth tug at the moon. The moon struggles between the two pulls making the plane of its orbit wobble slowly. This makes the position of the nodes themselves shift backwards from year to year. So the eclipse seasons are not always the same. They shift continuously from year to year! This changes the earth—moon and the earth—sun distances at every eclipse, making them of different length, different type and visible from a different place. In addition there are

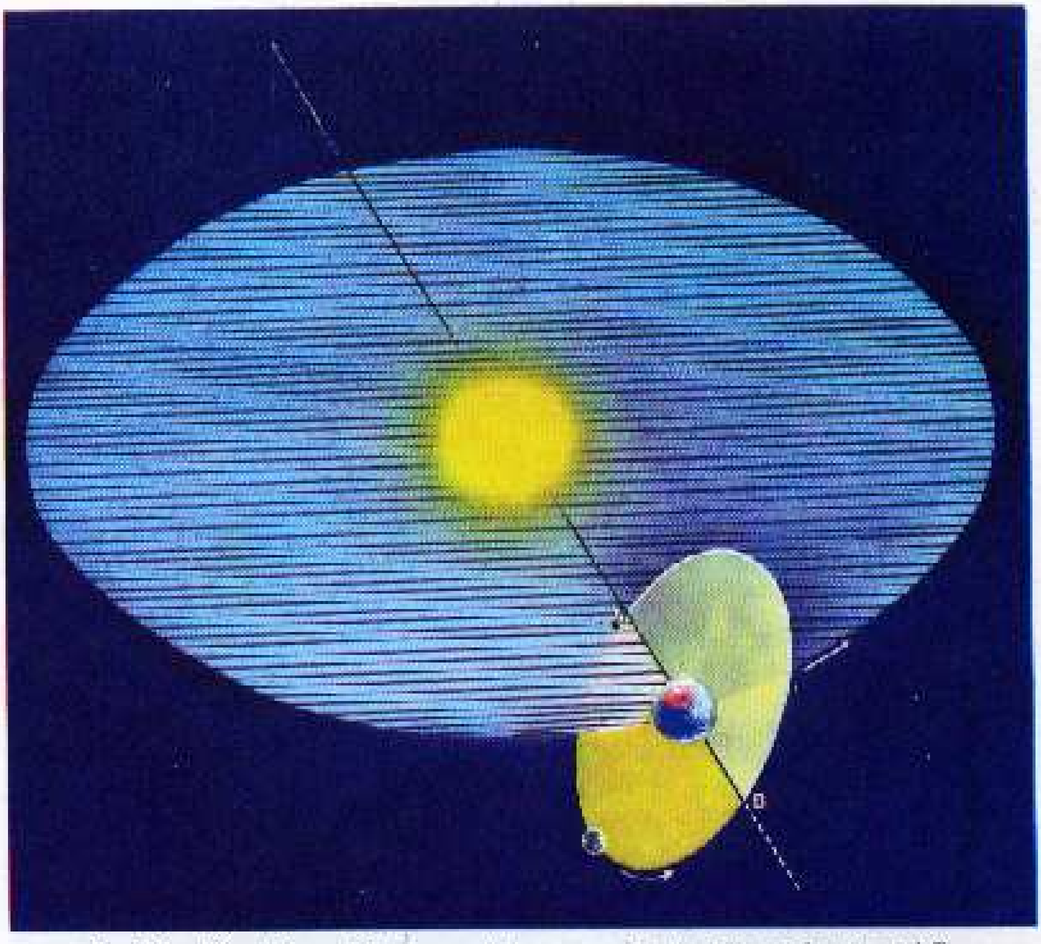


Fig. 26 : Tilt of the orbit plane of the moon. Notice the nodes A and B

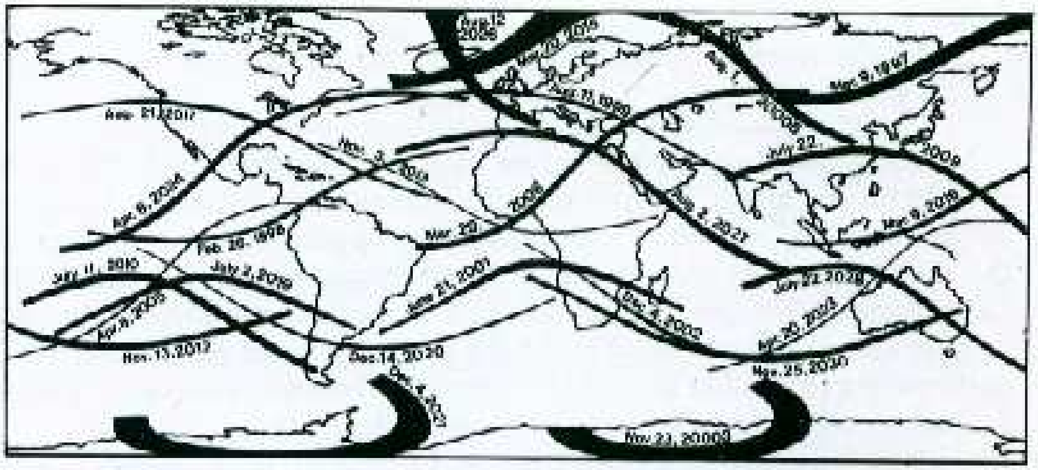


Fig. 27 : Paths of total solar eclipses till 2016

several other subtle corrections that have to be made before an accurate prediction, correct to within 5 seconds, can be made.

It has been found that the sun, the moon and the earth come to the same relative position after 18 years and 11.3 days. After this interval similar eclipses occur. But notice that extra 0.3 days over the 11 days. In this 0.3 days the earth rotates by 120 degrees and so this eclipse is visible from a different part of the earth. This interval is known as the saros. All eclipses separated by an integral number of this interval belong to the same family.

In any year there have to be at least two eclipses, both solar. The maximum number of eclipses in a year can be seven, five solar and two lunar. A total solar eclipse is, however, not so common. Three are visible somewhere in the world, every two years. But the path is so narrow that any one place experiences a total solar eclipse only very rarely, approximately once in 360 years. Only three total solar eclipse paths pass through India in the 20th century, those of February 16, 1980, October 24, 1995 and August 11, 1999.

The shadow cast by the earth falls on man made satellites too. During their 'eclipse' their solar panels do not receive sunlight. For a geostationary satellite like INSAT this happens on the equinox days as that is when the satellite is at the nodes and in the same plane as the earth. Transmission is temporarily stopped to conserve electric power. If this happens during an exciting cricket match in Australia you miss the live telecast via satellite!

Let's Predict an Eclipse

What you need

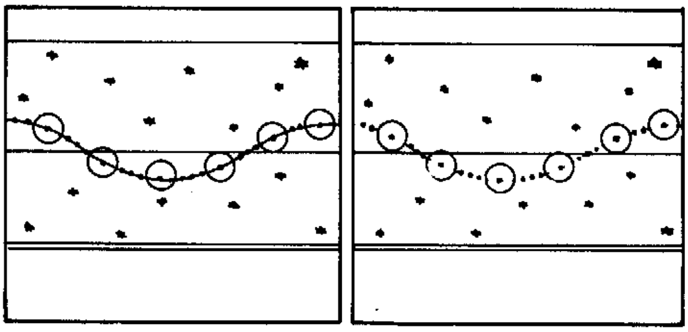
Pictures from the page 72 and tables from this page
A pencil

Each picture shows the set of star patterns that form the background for the moon. The position of the moon is shown in each picture for one month. The line in the centre is the apparent path of the sun in the sky. It is called the ecliptic. It is the projection of the path of the earth around the sun. Notice how the moon is sometimes above the ecliptic and at others below it. At the node it crosses the ecliptic. This path came to be called the ecliptic because whenever a lunar or a solar eclipse occured the moon was near or on this path!

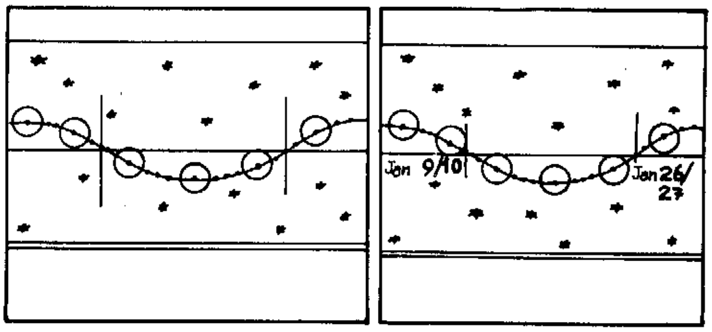
New and Full moon dates for January to June 1996

New Moon		*Full Moon*	
January	20	January	6
February	19	February	4
March	19	March	5
April	18	April	4
May	17	May	3
June	16	June	2

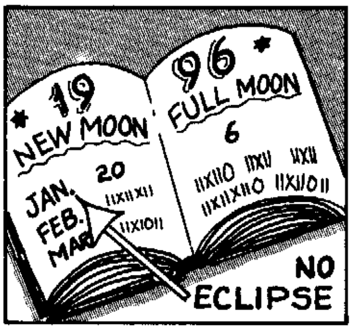
What to do



1. Mark where the smooth curve crosses the central line of the ecliptic. These are the nodes or *Rahu* and *Ketu*.



2. Note the dates on which the moon is at the nodes.



3. Check from the table if the moon is full or new on these dates. If it is, then there will be an eclipse. Otherwise there is no possibility of an eclipse!

4. Repeat for rest of the pictures and predict eclipse dates for the first six months of 1996.